The Citrus industry / edited by Walter Reuther, Herbert John Webber [and] Leon Dexter Batchelor with the collaboration of J. Henry Burke [and others].

[Berkeley] : University of California, Division of Agricultural Sciences, 1967-1989.

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THE CITRUS INDUSTRY

VOLUME III

Production Technology

EDITED BY:

Walter Reuther

Professor of Horticulture and formerly
Chairman, Department of Horticultural Science,
University of California, Riverside, California

WITH THE COLLABORATION OF:

Robert G. Platt • Karl W. Opitz
Winston W. Jones • Tom W. Embleton
Charles K. Labanauskas • Herman J. Reitz
Lowell N. Lewis • C. Dean McCarty
Albert W. Marsh • Franklin M. Turrell
Lowell S. Jordan • Boysie E. Day

Revised Edition

University of California

Division of Agricultural Sciences

1973

Library of Congress Catalog Card No. 67-63041

Printed in the United States of America

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DEDICATED TO

LEON DEXTER BATCHELOR

and

WILLIAM HENRY CHANDLER

pioneers and leaders in transforming horticulture from an art to a science

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LEON DEXTER BATCHELOR

(1884-1958)

"The impact of Dr. Batchelor's vision and research will remain a monument to him not only in California but in all parts of the world where citrus is grown."

—A. M. BOYCE

Immaculately dressed, a Stetson on his head, Leon Dexter Batchelor is remembered astride a horse during his leisure hours, riding between furrows of the orange or walnut orchards of the old Citrus Experiment Station, jotting notes on the vigor of a promising nucellar clone, observing a gopher hole that the field men had missed, finally turning his horse out of the groves and up into the hills beyond. To some he was always a lonely or aloof man in the saddle—the general on horseback who never let go of the reins. Very few of his staff viewed him in that light, however. Beyond the slight touch of New England reserve, they found inspiration in his smile, his dry humor, his positive outlook on any scientific problem, the sense of stability and tradition he brought to the station for over two decades as its director.

He was a man chosen at the right time—picked on the eve of the stockmarket crash. In the five years prior to his appointment in 1929, the Citrus Experiment Station budget climbed by sixty per cent during a heady period of expansion. In the next decade, the budget fluctuated, often downwards, only once reaching as high as six per cent above the peak budget prior to the Depression. Batchelor's task was formidable, but he managed to steadily increase the research scope of the station, guided it through the era of its most impressive accomplishments since its founding, and maintained a creative, energetic staff. He made friends and sometimes he made enemies—largely because of disagreement over basic issues—but above all Batchelor preserved intact the important values of a great scientific institution, leaving his successors a solid heritage

WILLIAM HENRY CHANDLER

(1878-1970)

"The value of our work to society, however, is measured most largely by the new truth that we supply, by the effectiveness of our research, and effectiveness in research is not measured by cleverness with research tools. Research is not merely invention. It is searching a system of knowledge for gaps in it, and making carefully planned studies to fill those gaps."

—WILLIAM HENRY CHANDLER

When William Henry Chandler began his studies as a horticulturist around the turn of the century, there were few chairs of horticulture in the nation's colleges and universities, and the discipline had more of the characteristics of an art than a science. In the application of scientific methods to horticultural problems, Chandler was one of the influential pioneers whose concerted efforts exerted a revolutionary effect on the development of horticultural science.

A perceptive thinker with a gift for expression in both speech and prose that had a Thoreau-like eloquence, he stimulated several generations of horticulturists not only in the classroom but through his widely used textbooks. A strong streak of New England transcendentalism was apparent in Chandler's personality and a selflessness that was mirrored in his own evaluation of his work: "Whether my part is visible through the oil-immersion lens or not even to the electron microscope, it will find its true place regardless of any padding or strutting about I am foolish enough or irreverent to do."

Chandler was born in a one-room log cabin on July 31, 1878, near Butler, Missouri, the son of a Civil War veteran, Winfield Scott Chandler, and a Baptist minister's daughter, Mary Wade. Although not lacking in ambition, his father was ill-suited to a lonely farmer's life in rural Missouri. He needed friends and the presence of crowds,

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on which to build in the post World War II period.

Leon Dexter Batchelor was born on a small farm in Upton, Massachusetts, on May 8, 1884, a member of an old New England family with American roots in the seventeenth century. From early childhood he was fascinated by horses, and he entered New Hampshire Agriculture and Mechanical College determined to seek a career in animal husbandry. It was there that Dr. Harry F. Hall, assistant horticulturist, influenced him toward pursuing horticulture as a profession.

Batchelor received the B.S. degree in 1907 and went on to Cornell University, serving as an instructor in horticulture from 1907 to 1910, and completing the Ph.D. in 1911. At Cornell, he attracted the attention of Herbert John Webber, soon to become the first director of the University of California Citrus Experiment Station (now the Citrus Research Center and Agricultural Experiment Station). Batchelor was one of a team of outstanding Cornell graduates that Webber was later to bring to California. He also made the acquaintance of the famed Liberty Hyde Bailey, joining other promising students on Sundays at the horticulturist's home. Throughout his academic career, a photograph of Bailey was a permanent fixture in Batchelor's office.

From 1910 to 1915, Batchelor held the position of horticulturist at Utah Agricultural College, where he conducted research on apples and on effects of temperature on fruit-growing in mountain terrain. In 1915, he accepted the post of assistant professor of plant breeding at the Citrus Experiment Station, Riverside, becoming one of the small group of pioneer workers in the original laboratory that occupied the slopes of Mt. Rubidoux prior to the selection of the present station site. As a junior man at the Rubidoux Laboratory, Batchelor found that the major citrus research tasks had already been allocated. He was given English or Persian walnuts, which were becoming a significant tree crop in California, but which other workers viewed as an unwelcome assignment, since long daily trips to Whittier and other areas where walnuts were grown meant many hours of travel without added pay. "I've been handed a lemon," he told his young wife, Florence, "but I'm going to make lemonade out of it!" Batchelor was soon carrying out pioneer research and publishing extensive materials that

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and often would drop his plow in the middle of the field and go off to town to seek company. He lost his first farm when William was still a young boy, and from then on the family worked a succession of rented farms. By the age of eleven, William and a younger brother were doing most of the farm work, making the living for a family of eight.

After attending country schools, Chandler completed two years at an academy in Butler. Studying continuously in his spare time, he read widely both in literature and agriculture. He soon found employment teaching in a small schoolhouse. After several years of teaching, he successfully passed an entrance examination and in 1901 enrolled in the University of Missouri, receiving his B.S. degree in 1905. As a graduate student, he specialized in horticulture, receiving the M.S. degree in 1906 and the Ph.D. in 1913.

Between 1906 and 1923, Chandler taught at the University of Missouri, rising from instructor to assistant professor. In 1911, he joined Cornell University as a professor of pomology, and from 1920 to 1923 he served also as director of research for that university's Geneva Experiment Station. He moved to Berkeley in 1923 as a professor of pomology at the University of California and chairman of the Department of Pomology. He held the latter position until 1933, when he resigned as department head to devote more attention to research.

In 1938, despite his dislike for administrative duties and because of special circumstances, Chandler accepted the top administrative post of assistant dean of the College of Agriculture for the southern California campuses, with his headquarters on the Los Angeles campus. He continued in administration until 1943, and from 1938 on also held the position of professor of horticulture at Los Angeles. Even after becoming professor emeritus in 1948, Chandler remained professionally active for many years, preparing new editions of his books, writing, and consulting with numerous colleagues who valued his incisive judgment.

During his career, Chandler carried out both basic and applied research in almost every phase of horticultural science, and was a leading

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were quickly recognized as guideposts for the walnut industry. His studies, centered around improvement of harvesting methods and introduction of artificial dehydration, resulting in a striking increase in the quality of walnuts. His exhaustive investigations of soil-moisture relationships to nut size resulted in irrigation recommendations enabling growers to materially improve the size of walnuts. His irrigation studies also solved the walnut "dieback" problem by indicating that irrigation was needed in the winter period when trees were considered to be dormant. Batchelor's extensive California research, backed by studies in Europe and the Near East, brought him prominence as a world authority on walnut culture.

In 1919, Batchelor's work was given wider scope and he became professor of orchard management. One of the first agricultural researchers to recognize the value of statistical methods and good field plot designs, he launched many of the longterm orchard fertilizer experiments that led to more efficient fertilizer practices in California's tree fruit industry.

In 1929, following Webber's retirement, Batchelor was named director of the Citrus Experiment Station. He served as its administrator for twenty-two years until July 1, 1951. In spite of heavy duties as director, he continued to supervise a number of research projects, such as citrus rootstock investigations and a study of performance behavior of nucellar and other clonal lines of oranges and lemons. An outstanding example of his later research work is the Troyer citrange, which he helped develop as an important rootstock for oranges.

As director of the experiment station, Batchelor had a sound sense of which problems were significant and which trivial or possibly beyond the capabilities of the station. His cautious judgement was not easily influenced by outside pressure toward allocating research resources to projects he considered marginal for success. His approach to major problems, however, was always decisive. When tristeza disease or "quick decline" first appeared in Southern California, Batchelor swiftly mobilized all of the station's skills for a broad interdisciplinary attack on the disease that eventually led to the discovery of Fawcett and Wallace that a virus was the causal agent. His own reappraisal of earlier studies on the replant problems in old citrus soils

innovator in applying scientific methods to horticultural problems. Many of his journal articles are today considered classics, and still are frequently cited although the research was conducted from thirty to sixty years ago.

Chandler's best known research activities were related to studies of the killing of plant tissues by freezing, pruning, the effects of fruiting on trees, little leaf disease (zinc deficiency), and chilling requirements of fruit trees. His discovery with D. R. Hoagland of zinc deficiency as the cause of little leaf disease in deciduous fruit trees opened up the new field of study of microelements as major restraining influences on the vigor and growth of fruit trees. When he began research on pruning, it was still essentially an art dependent upon lore handed down through the ages; his randomized and replicated experiments revolutionized the concepts of pruning effects on plants. His studies of the rest period and cold-hardiness of deciduous fruits led to the establishment of climatic requirements for such fruits and the abandonment of attempts to grow deciduous fruits in many unsuitable climates.

One of the great classics of horticultural science is Chandler's *Fruit Growing*, published in 1925, where he pioneered the use of plot designs and statistical methodology in horticultural research. No publication in horticultural history had ever before so effectively and completely evaluated research findings in such a broad area. Other important and influential books by Chandler were *North American Orchards, Deciduous Orchards,* and *Evergreen Orchards.*

Chandler was the last great generalist in horticulture, and some of his finest contributions are not easy to record, since they consisted of a contagious enthusiasm that stimulated students and colleagues to pursue his suggestions and make new discoveries. He was always accessible to everyone, and his wealth of knowledge and always constructive criticisms inspired several generations of researchers.

According to colleagues, he had an ideal research point of view, because he never assumed any scientific matter had been settled and despite personal biases was always capable of utter objectivity in analyzing any problem. Some of this quality is captured in a remark he once made: "I liked the part in one of George Bernard Shaw's

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prompted Batchelor to add a soil microbiologist and later a nematologist to his staff. The new line of inquiry into the role of biological organisms in the soil finally resulted in a greater understanding of the nature of "soil fatigue" in old citrus orchards and the introduction of soil fumigants to orchard practice.

Batchelor published extensively in many scientific journals, but he is best known as the co-editor with H. J. Webber of the first edition of the monumental two-volume classic, *The Citrus Industry,* which has had worldwide influence on citrus culture. He was a member of the American Association for the Advancement of Science, the American Society of Horticultural Science, and Alpha Zeta.

Outside of his profession, Batchelor's deep and scholarly interest in the history of the West made field trips memorable to colleagues, since he enjoyed imparting his knowledge of historic spots encountered to those accompanying him on journeys. His enthusiasm for horse racing always astonished new staff members, who initially viewed him as somewhat austere. Only harness racing appealed to Batchelor, probably because the three heats reduced chance aspects, making it possible for him to ally his love for horses with his interest in statistical probability. He enjoyed taking staff members to the races and exhibiting his skill at picking winners, but he always confined his betting to cigars. On one occasion he summed up years of study of the sport for a young horticulturist, Dr. W. P. Bitters. "Willard," he observed, "the unbeatable combination is an Irish driver and a Hanover horse."

During his thirty-eight years of service to the University of California, Batchelor saw the Citrus Experiment Station grow from its early years with a staff of seventeen and thirty acres of land to a staff of over 275 people and over 900 acres when he retired in 1954. Although Batchelor's contributions to agricultural research were significant, his greatest accomplishment was undoubtedly the administrative skill he wielded in carrying the Citrus Research Center and Agricultural Experiment Station from its adolescence to maturity and recognition as one of the outstanding agricultural research centers of the world. That effort was memorialized in 1967 when the newly completed Batchelor Hall was dedicated in his honor on the Riverside campus of the University of California.

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plays where the bishop advised people always to give the devil a chance to state his case, for I have come to believe that the devil has a rather strong case. He stands for selfishness, and a degree of selfishness is socially necessary; for the most diligent care of each individual. Furthermore, we need something to struggle against."

Chandler was the recipient of numerous honors, including his election in 1921 as the thirteenth president of the American Society for Horticultural Science, election to the National Academy of Sciences in 1943, and unofficial selection as one of America's three great horticulturists as reported by the *American Fruit Growers' Magazine* in January, 1948. He was also awarded the Wilder Medal of the American Pomological Society in 1948, the Charles Reid Barnes Life Membership Award of the American Society of Plant Physiology in 1951, and an honorary degree from the University of California, Los Angeles, in 1949.

The esteem in which he was held by his colleagues is perhaps best exemplified by the tribute paid to him following his death in 1970 in an obituary in *HortScience:* "William Henry Chandler was truly a giant of his time. His contributions to horticulture and to those of us who came under his tutelage cannot be measured. We can, however, make note of his eminence and express our appreciation for all he has meant, and our devotion to him as a friend, colleague, and mentor. To his children and their families, we in the American Society for Horticultural Science express our gratitude for his inspiring leadership and his manifold contributions to our understanding of the specific responses of horticultural plants. We are eternally indebted to him that he chose horticulture as his profession."

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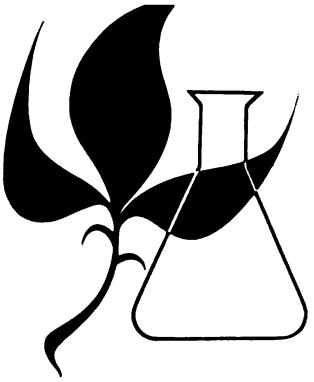

PREFACE

Since each of the four volumes of the revised and new edition of *The Citrus Industry* is complete in itself, the general plan of the work must be restated in each volume. The first volume of the revised edition, *History, World Distribution, Botany, and Varieties,* was published by the University of California Division of Agricultural Sciences in 1967. The second volume, *Anatomy, Physiology, Genetics, and Reproduction,* followed in 1968. These first two volumes covered much of the subject matter originally presented in Volume I of the first edition, plus some additional material. This third volume, *Production Technology,* encompasses orchard management portions of the subject matter originally covered in Volume II of the first edition. The fourth volume, *Crop Protection,* will cover those portions of Volume II of the first edition that were concerned with the biology and control of pests and diseases. None of the chapters in this volume on production technology are revisions of chapters in Volume II of the first edition; all are completely new treatments of the subject matter by a new generation of authors.

The first edition of *The Citrus Industry* served for more than two decades as the classic reference work on the biology and culture of citrus throughout the world. The first volume, *History, Botany, and Breeding,* edited by H. J. Webber and L. D. Batchelor, was published by the University of California Press in 1943, and was followed by two later reprintings. A larger printing of the second volume, *Production of the Crop,* edited by L. D. Batchelor and H. J. Webber, was published in 1948 by the University of California Press. By the early 1960's, it had become apparent that many sections of the original volumes had been rendered obsolete by technological advances and the acquisition of new basic knowledge merely touched upon or not considered in the original edition.

Prompted by Dean A. M. Boyce and other colleagues, I agreed to serve as editor for a new, revised edition. Revision of *The Citrus Industry* was initiated on July 21, 1961, as Citrus Research Center and Agricultural Experiment Station Project 2015 at the University of California, Riverside. Because of substantial expansion of coverage, it became necessary to increase the number of volumes from two to four. Thus, the present volume includes much of the subject matter that originally appeared in the second volume of the first edition. The chapters presented here reflect the much broader base of experience and information available to the new authors as a result of the increased tempo of citrus research in the decades since World War II.

All except one of the authors of chapters in this volume are members of the staff of the University of California and are affiliated with the Citrus Research Center and Agricultural Experiment Station at Riverside or with the University of California Agricultural Extension Service. Their treatment of subjects therefore tends occasionally to exhibit a regional perspective, although improved communications and transportation in the past few decades has made it possible for citrus researchers and specialists to be more cognizant of developments in other countries than was the case for contributors to the original volumes.

The four volumes of the new revised and expanded edition of *The Citrus Industry* are intended to present a comprehensive view of all phases of the industry to a broad readership of researchers, administrators, advisors, teachers, students, and knowledgeable growers. An effort has been made to present all material clearly, yet scientifically, so that it might be understood by an intelligent and informed readership. The editor, however, considered it essential that scientific principles on which various practices are based should also be explained. Some parts of this volume, therefore, may present material of a highly technical nature best followed by specialists. Literature reviews for most chapters in the volume were completed with 1971 citations, although some authors were permitted to add significant new material during proof-reading of page proofs.

Production technology as presented in this volume encompasses most of the phases of citrus orchard development and management except control of pests and diseases.

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Chapter 1, "The Propagation of Citrus," by Robert G. Platt and Karl W. Opitz, provides a modernized and expanded treatment of citrus propagation. It also describes some recently developed methods of propagation, such as shoot apex micrografting, which may have great significance in disease elimination and quarantine procedures of the future.

Chapter 2, "Planning and Planting the Orchard," by Robert G. Platt, presents modern information on site selection, planting distances, topography and soil influences, use of windbreaks, and related considerations of importance in locating and establishing an orchard.

Chapter 3, "Weed Control," by Lowell S. Jordan and Boysie E. Day, presents the methods and technology of chemical weed control, largely developed since World War II, as well as a discussion of mechanized weed control.

Chapter 4, "Soils, Soil Management, and Cover Crops," by Winston W. Jones and Thomas W. Embleton, summarizes current information and practices in the field of orchard soil management. Modern practices that have evolved during the past twenty-five years differ significantly from those outlined in the original 1948 volume because of mechanization, technological advances, and economic pressures such as high labor costs.

Chapter 5, "Orchard Fertilization," by Thomas W. Embleton, Herman J. Reitz, and Winston W. Jones, provides an up-to-date review of soil fertility research with citrus and outlines the nutritional restraints and fertilizer practices employed in modern citrus orchards. Spectacular advances have been made during the past three decades in the field of mineral nutrition of crop plants generally, and citrus species in particular. Thus this chapter presents more authoritative information grounded on a much broader base of basic and applied research than does the analogous chapter in the 1948 edition.

Chapter 6, "Leaf Analysis as a Diagnostic Tool and Guide to Fertilization," by Tom W. Embleton, Winston W. Jones, Charles K. Labanauskas, and Walter Reuther, includes a new technology (plant analysis) in the culture of citrus which has been developed largely during the last three decades. It has been widely used as a research and orchard management tool only during the past fifteen years. This chapter should be particularly valuable in identifying and correcting nutritional restraints to citrus production in new areas, especially in countries with little information on the fertility status of their soils.

Chapter 7, "Pruning, Thinning, and Girdling of Citrus," by Lowell N. Lewis and C. Dean McCarty, reviews the much expanded research information on these ancient methods of manipulating growth and fruiting behavior of tree fruits. Mechanization, chemical growth regulators, and certain research developments, including changing economic pressures, have caused some sweeping changes in these manipulative practices in citrus orchard management since those outlined in the 1948 edition were written.

Chapter 8, "Irrigation," by Albert E. Marsh, reviews modern knowledge on citrus moisture requirements and the physiological implications of moisture stresses occurring at various stages in the development of the tree and the fruit. The energy concept of soil moisture availability is incorporated in the instrumentation and irrigation techniques described. Possibilities of developing mechanized and automated methods of irrigation are reviewed. All in all, this chapter bears little resemblance to its counterpart of the 1948 edition.

Chapter 9, "Climate and Citrus Behavior," by Walter Reuther summarizes the somewhat incomplete knowledge available concerning bioclimatic influences, especially energy-related ones, on the growth, fruiting, and physiological behavior of citrus species. Also, climatic parameters for commercial citrus culture are reviewed. Much new information is presented which was not available when this subject was treated in the 1948 edition.

Chapter 10, "The Science and Technology of Frost Protection," by Franklin M. Turrell, presents a comprehensive treatment of modern citrus orchard frost protection practices and technology, as well as the basic physics and physiology of frosts and freezes. The emergence of the wind machine as an efficient frost protection tool during the last two decades reflects the impact of engineering advances and economic pressures which were unexploited or unknown when frost protection methods were discussed in the original chapter in the 1948 edition.

A projected chapter on rootstocks, through an unfortunate set of circumstances, was not available for inclusion as this volume went to press.

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The editor wishes to express his deep appreciation to the authors of the various chapters for their wholehearted cooperation and patience during the preparation of this volume. A number of authors also found time despite their busy schedules to assist in the review of chapters by their colleagues. Gratitude must also be expressed to those colleagues at Riverside and in other institutions too numerous to list who assisted in reviewing all or parts of the text dealing with their particular specialities and fields of research.

WALTER REUTHER
Riverside, California
August 19, 1972

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CHAPTER 1

Propagation of Citrus

ROBERT G. PLATT and KARL W. OPITZ

CITRUS PROPAGATION DOES NOT differ greatly from the general techniques used in the propagation of other tree crops. Certain details, however, are unique and apply only to citrus. For this reason, an understanding of these specific details is necessary for the successful production of citrus nursery stock.[1]

In most areas, a citrus tree is produced by budding the desired scion variety into the chosen seedling rootstock. In some areas, however, and for special situations, other methods of propagation are used. Grafting, rather than budding, for example, gives satisfactory results, but is generally more difficult and time-consuming. Also, producing trees by cuttings, layers, and marcotts is successfully practiced under some conditions, but only to a relatively limited extent.

Regardless of the method employed, the production of well-grown, compatible, disease-free, true-to-type trees requires systematic and detailed attention. This chapter discusses the various propagation methods used, their application to certain conditions, and their advantages and disadvantages.

PRODUCING A BUDDED TREE

Growing the Seedlings

The seed used for seedling rootstock propagation varies with local conditions and requirements. Widely used in many citrus areas have been seeds from sweet orange, sour orange, grapefruit, shaddock, rough lemon, trifoliate orange, Troyer citrange, Cleopatra mandarin, and Sampson tangelo. Seed of other species and varieties, however, is used extensively to propagate rootstocks in certain areas of the world. These include, for example, the Rangpur lime in Brazil, the sweet lime in Israel, the Calamondin in the Philippine Islands, and the Yuzu in Japan. Currently, many other *Citrus* species, varieties, and relatives are being evaluated as rootstocks. Seed from some of these will undoubtedly be selected for future use.

Selection of Seed.—Each of the above species and varieties have certain characteristics of vigor, disease resistance or tolerance, nematode tolerance, compatibility with the scion, drought resistance, cold hardiness, tolerance to salinity, effect on scion fruit size and quality, and other desirable features. Seed selection, therefore, must be made toward using the species or variety which provide the greatest number of desirable characteristics necessary to meet the orchard conditions under which the tree will grow.

In addition to choosing seed from the species or variety known to provide desirable characteristics, it is important that only selected trees be used as seed sources. It is recognized that

[1] Important references on general citrus propagation not specifically cited in the text include: Webber (1948*a*), Johnston, Opitz, and Frolich (1959), McCown (1959), van der Meulen, Malan, and Naudé (1954), and Opitz, Platt, and Frolich (1968).

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certain varieties of citrus have more desirable attributes than others. For example, in trials to determine resistance to the burrowing nematode, *Radolphus similis* (Cobb) Throne, Ford, and Feder (1961) found that the California selection of Carrizo citrange was more resistant than either the Florida or Texas selections. Also, it is recognized in California that seeds from certain varieties of sweet orange, grapefruit, and sour orange produce seedlings of greater vigor and more uniformity than others (Platt, 1956).

Freedom from disease is also an important consideration. Until recently, evidence indicated that very rarely were known virus diseases transmitted through citrus seed (Weathers and Calavan, 1959). Within the last few years, however, investigators have suspected seed transmission of psorosis (Bridges, Youtsey, and Nixon, 1965; Pujol and Beñatena, 1965) and have confirmed that the virus was transmitted through seed from infected Carrizo citrange trees (Childs and Johnson, 1966). It is, therefore, imperative to use vigorous trees that have remained free of disease as the seed source.

Even though heat treatment (discussed later) reduces the possibility of infection by *Phytophthora* fungi, contamination should be avoided by picking seed fruit from the tree. Fruit that has fallen is more subject to brown-rot infection. Seed in rotten fruit may be invaded by fungi that later contaminate the seedbed.

Care must be taken that trees of a certain clone are, in fact, of the clone desired and not seedling trees only appearing to be the same. Bitters (1961) pointed out the difficulties existing with Troyer citrange. Some Troyer citrange seed-source trees have been grown as seedlings, not as budded trees from known Troyer citrange clones. Even though Troyer citrange is highly nucellar, some gametic seedlings are produced. Progeny from gametic Troyer citrange trees will not be identical to those of the true Troyer citrange clone and may have undesirable characteristics from the standpoint of growth habit, disease or nematode resistance, or compatibility with the scion.

Seed from frosted or frozen fruit is generally satisfactory for propagation if it is the only seed available, although the degree of viability depends upon the species of fruit and the severity and duration of the cold. Horanic and Gardner (1958), using Pineapple orange seed extracted from sound fruit, found no injury at 25° F, partial damage at 20° F, practically complete killing at 15° F. These temperatures were maintained for 24 hours during the test. Viability of seeds taken from severely-frozen fruit was reduced if the temperature within the center of the fruit reached the critical point for a sufficient period. In California, the authors have observed trifoliate orange and Troyer citrange seed germinate with no apparent loss of viability after having been frozen for several days.

Some knowledge as to the type of seedling growth of different citrus is desirable for subsequent nursery operations. Vigorous, upright seedlings are produced, for example, from sour orange, rough lemon, Rangpur lime, and Troyer citrange. A large percentage of sweet orange and grapefruit seedlings branch close to the ground and require frequent training to produce a straight trunk for budding. Cleopatra mandarin grows upright, but is slower in growth and somewhat more difficult to transplant. Sampson tangelo is even slower in attaining lining-out size and has a bushy habit of growth.

Floral characteristics were found by Shannon, Frolich, and Cameron (1960) to divide the trifoliate orange into two growth-habit groups. Seedlings from the small-flowered group were bushy with multiple trunks, while those from the large-flowered group were upright with a single trunk. The vigor of both groups, when allowed to grow naturally, was about the same. If the seedlings of the small-flowered group were suckered to develop a trunk for budding, however, they attained a weight and size only one-half that of the seedlings from the large-flowered group. These differences are most pronounced in localities having cool summers. With high summer temperatures, the small-flowered types grow nearly as large and similarly to the large-flowered types.

Extraction of Seed.—Citrus seeds are often extracted by making a shallow cut through the rind around the center of the fruit and twisting the two halves of the fruit apart. The seeds are then squeezed onto a sieve and washed free from the pulp.

Where large quantities of seed are required, various extractors are used, some hand operated and some mechanical. In general, these extractors tear the fruit apart, and the seeds are separated with water from the rind and pulp through a series of sieves and containers. The sound seeds, being of greater density, are sepa-

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rated from the underdeveloped seeds and pulp which float out.

Seed number and size of different kinds of citrus vary considerably. Even within the same variety differences occur. In California, for example, fruit from coastal districts usually contain fewer and smaller seed than fruit from interior districts. The number and size of seed from individual trees vary from season to season, and often more seed per fruit is found during heavy crop years.

Under average conditions, the number of seeds per fruit will likely be ten to fifteen with Troyer citrange and Sampson tangelo; fifteen to twenty with sweet orange, sour orange, and rough lemon; twenty-five to forty with trifoliate orange; forty to fifty with grapefruit; and twenty-five to thirty with Alemow (*Citrus macrophylla* Wester).

While variation in seed size makes measurement somewhat uncertain, the experience of many nurserymen indicates the approximate number of seed per quart or per liter to be as follows:

Rootstock	*Seeds per Quart or Liter*
Trifoliate orange	2,000 – 3,000
Grapefruit	2,200 – 2,500
Sweet orange	2,200 – 2,800
Alemow (*Citrus macrophylla*)	4,500 – 5,500
Sour orange	2,200 – 2,800
Troyer citrange	2,400 – 2,600
Rangpur lime	3,000 – 3,500
Rough lemon	5,000 – 7,000
West Indian lime	6,000 – 8,000
Cleopatra mandarin	5,000 – 6,000

Effect of Seed Treatment on Fungus Control, Germination, and Albinism.—Serious loss of seedlings in the seedbed and nursery row from infection by the fungi *Phytophthora citrophthora* (Sm. & Sm.) Leonian and *P. parasitica* Dastur may largely be prevented by two methods.

First, as previously mentioned, the seed should be extracted from fruit harvested directly from the tree. Second, the seed should receive a hot-water treatment. Klotz *et al.* (1960), working with seed from Cleopatra mandarin, CRC 343 grapefruit, Koethen sweet orange, and Standard sour orange, have shown that immersion of seed for 10 minutes in well-agitated water held at 125° F assures elimination of *P. citrophthora* and *P. parasitica*. In commercial practice, where large amounts of seed are involved, care must be taken to maintain the required temperature for the specified time (Newcomb and Hendrickson, 1966). That the hot-water treatment has little effect on viability, even on seed stored for a year, has been demonstrated by Nauer and Roistacher (1962).

In addition to the hot-water treatment, it is also common practice to treat the seed with a fungicide. Chemical treatment reduces possibilities of mold infection on stored seeds. With some chemicals, the occurrence of albinism and virescence in seed planted with or without storage is reduced or eliminated.

Albino or virescent seedlings, which often occur in citrus seedbeds, lack chlorophyl in various amounts. Albinism denotes a complete lack of chlorophyl and such seedlings do not survive. Virescent seedlings lack chlorophyl in the leaf veins or portions of the mesophyll of the first leaves. They sometimes recover, but growth is usually retarded.

In some instances, albinism is genetic (Torres, 1936). Recent evidence, however, indicates this is not usually the case, and that a fungus is responsible (Frost, 1948). Tager and Cameron (1957) found that albinos were eliminated by removing the seed coat, but when excised embryos were germinated in contact with seed coats, albinos often resulted. Durban (1959) found that *Aspergillus flavus* (Link) caused albinism in sweet orange and grapefruit seedlings when sterile seed was inoculated with this fungus. Ryan, Greenblatt, and Al-Delaimy (1961) produced albinism in seedlings by inoculating or bringing seed in contact with an extract of *Alternaria tenuis* Nees. It is suggested that a fungus in the seed coat produces a metabolite which, when taken up by the germinating seedling, inhibits chlorophyl biosynthesis (Durbin, 1959).

A number of investigators have studied the effects of chemical treatment on citrus seed, not only in relation to albinism, but also as it affects germination. These investigators have employed conventional inorganic salts of heavy metals such as copper sulfate, a group of newer heavy-metal carbamate fungicides, and some nonmetallic organic compounds. Perlberger and Reichert (1938) found that inorganic salts of heavy metals were effective in preventing albinism. Childs and Hrnciar (1948) reported that dipping seeds in a 1 per cent solution of 8-hydroxyquinoline sulfate resulted in over 90 per cent germination after storage for six months at 35° F in moist sawdust or moss in unsealed containers. Later investigators (Ryan and Stein, 1958), however, found that seed treated with 8-hydroxyquinoline sulfate declined rapidly in viability after one month's stor-

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age in sealed polyethylene bags or glass jars. This may be due to differences in the sealed and unsealed containers used for storage.

Ryan and Stein (1958), working with seed of Cleopatra mandarin, also used dusts of Fermate (76 per cent ferric dimethyldithiocarbamate), Phygon XL (50 per cent 2, 3-dichloro-1, 4-naphthoquinone), and Arasan (50 per cent tetramethylthiuram disulfide). These fungicides completely prevented the occurrence of albinism. After three months' storage, germination of the Fermate- and Phygon-treated seed was 90 and 80 per cent, respectively, as compared to 42 per cent for untreated seed. Germination of Arasan-treated seed after 12 months of storage was 76 per cent compared to 8 per cent for an untreated lot.

Said and Ryan (1961), using Parzate (65 per cent zinc ethylene-*bis* [dithiocarbamate]), Captan (50 per cent *N*-trichloromethylmercapto-4-cyclohexene-1, 2-dicarboximide) as well as the fungicides used by Ryan and Stein, had essentially the same results with Cleopatra mandarin seed. With sweet orange seed however, they found that Fermate failed to prevent albinos and Captan produced more albinos than did untreated lots. With grapefruit, both Captan and Fermate produced more albinos than untreated seed. In these trials, they reported that Captan increased bench root.

Currently, the chemical treatment widely used by California nurserymen is dusting of the seed with Arasan. This fungicide is used both for seed planted immediately or stored up to several months. Where seed is to be planted not longer than a few weeks after treatment, 8-hydroxyquinoline may be used as a dip (Ryan and Frolich, 1961; Moore 1961). Dusts are generally more convenient and therefore often preferable to liquid preparations. Dried sufficiently to remove surface moisture, the seed is placed in a suitable container, a fungicide dust is added, and the seeds in the container are shaken to thoroughly coat them. (Polyethylene bags make ideal seed storage containers.)

Storage of Seed.—With the exception of the trifoliate orange, most citrus seed gives the highest germination if planted immediately after extraction from mature fruit. Often, however, it is necessary to store citrus seed, since many seed varieties mature during the fall and winter while planting is usually done in the spring.

The seed must not be allowed to dry out, either immediately after extraction or in storage. Seed of the trifoliate orange is particularly sensitive. Under California conditions, only one-half hour in the sun or three hours indoors noticeably reduces germination (Ryan and Frolich, 1961). In germination tests with trifoliate orange, Fu (1951) demonstrated that germination dropped sharply when the moisture content fell below 70 per cent. Chapot (1955) found that 50 per cent of trifoliate orange seed germinated if stratified for six months in humidifiers at 4° C and only 3 per cent when seed was dried and stored at the same temperature.

Seeds from other citrus species vary in the amount of drying they will tolerate without impairment of germination. Bacchi (1958) reported that seeds of Rangpur lime and sweet orange stored best in closed containers at 2° to 3° C in a very humid atmosphere. In Brazil, Montenegro and Salibe (1960) found that seeds of the Caipira orange, sour orange, rough lemon, Cleopatra mandarin, and the trifoliate orange germinated poorly when allowed to dry out in storage. Ryan and Frolich (1961) reported that Troyer citrange in California is very sensitive to drying and although certain other species such as rough lemon show some resistance to drying, up to 50 per cent of the seeds may become nonviable in the first two or three days of exposure to drying conditions. Even in the humid climate of Ceylon, Richards (1952) found that the germination of Country lime (West Indian type) and Bibile sweet orange declined steadily when seeds were kept in the open at a temperature of 78° to 80° F for two or more days after extraction.

It is inadvisable to store seed in the juice of the fruit. In Israel, Elze (1949) found that germination was often reduced by keeping seeds of Palestine sweet lime, sour orange, rough lemon, and trifoliate orange in the fruit juice. Nurserymen in California have also experienced failures with seed stored in its own juice.

Seed to be stored is washed to separate it from the juice and pulp and then given the hot-water bath for *Phytophthora* prevention. Surface moisture is then removed by spreading the seed on a cloth or screen in a shady place. An electric fan hastens surface drying and lessens the need for long exposure and internal drying of the seed to dangerous levels. In very humid climates, of course, there is less danger of overdrying and seed may be exposed for longer periods without harm.

The seed is next treated with a suitable fungicide and placed in a container which pre-

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vents further loss of moisture yet does not interfere with gas exchange. Polyethylene bags sealed with a rubber band are ideal for such seed storage. Seed may also be successfully stored if placed in moist sawdust or moss in unsealed containers (Childs and Hrnciar, 1948). When kept moist in such containers, seed of most species may be successfully stored for as long as eight months.

Successful storage temperatures used by various investigators have ranged from 35° to 45° F. Mungomery, Agnew, and Prodonoff (1966) found that seed germination percentages declined with storage temperatures above 50° F. Many nurserymen and seed suppliers store at temperatures of 40° to 45° F.

The viability of seed, either fresh or stored, may be determined before planting. Monselise (1953) found that staining peeled seed with a selinite-indigo carmine solution produced a red color in live tissue and a blue color in dead tissue. More recently, a viability test using 2, 3, 5-triphenyltetrazolium chloride (TTC) has been described by Roistacher and Nauer (1961, 1962). The enzymes present in live tissue react with this chemical to form an insoluble red dye. Dead tissue remains a natural color.

Preparation of Seedbed.—There are several important factors in selection of the most desirable site for the seedbed. The best soils are fertile sandy loams at least 12 inches deep with good internal water drainage. The soil should be free from gravel and stones, slightly acid (Martin and Page, 1962), low in soluble salts, and virgin to citrus. Although under some conditions seedbeds are successful on soil previously used for citrus, in most areas a second crop of citrus on the same soil results in poor growth (Martin, 1949). Such soils have been called "old citrus soils" and are those which have had citrus roots in them any time within the previous fifteen to twenty years. A warm site with good air drainage reduces the need for winter frost protection. Since the seedbed must be frequently tended, a location easily accessible and convenient is best. Locating the seedbed some distance from established citrus plantings will minimize the possibility of pest infestation or infection from disease.

Since it is often difficult to find a location that meets all the desirable criteria for an ideal seedbed, modifications of available conditions are often necessary. Clay soils, for example, may be improved by adding sand and neutral or slightly acid peat moss. Sandy soils are made more retentive of moisture and nutrients by the addition of large amounts of peat moss. A ratio of one part peat moss to three parts of sandy soil by volume is satisfactory. The addition of manures or leaf mold to seedbed soil is usually avoided because it may introduce unwanted salts and fungi.

Where only small lots of seeds are to be planted, boxes of a convenient size may be used. With this type of seedbed, it is possible to mix an ideal soil for filling the boxes. Reid (1955) suggested a mixture of sterilized loam soil, peat moss, and sand in the ratio of 4:2:1.

If the only soil available is one which has previously grown citrus, thorough fumigation is required to eliminate fungi and citrus nematodes. Standard practice with some nurserymen regardless of past soil history is to fumigate all soil on which citrus stock is grown. This practice also eliminates weeds.

Under special programs, soil fumigation is required. Regulations of the California State Department of Agriculture Nursery Service, for example, require that all soil used for the propagation of citrus seedlings entering the citrus certification program "be treated for soil-borne pests in an approved manner." (See Mather, 1963.)

Several materials are satisfactory for effective soil fumigation. Commonly used fumigants

Fig. 1–1. A barley nurse crop, sown with the citrus seed in large open beds, protects the seedlings as they emerge.

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Fig. 1–2. Citrus seedbed arrangement using broad flat furrows with seed planted in bottoms. Note remains of barley nurse crop used to provide shade for emerging seedlings.

and their dosage rates per 100 square feet are: methyl bromide at 4 pounds; 1-3-dichloropropene and 1-3-dichloropropane mixture (DD), at 1.5 to 3 pounds; and Vapam (sodium *N*-methyldithiocarbamate dihydrate), at 1 quart in 400 gallons of water. Steam sterilization of the soil is also effective. When chemical fumigants are used, a waiting period is necessary for the material to dissipate. The length of time needed for the soil to become free of toxicity depends upon the fumigant used, its concentration, and soil temperature, moisture, and texture.

Occasionally the growth of seedlings in fumigated or heat-treated soil is temporarily retarded. Martin (1962) and Martin, Baines, and Page (1963) found retardation was associated with the inhibition of phosphorus absorption and the reduction of copper and zinc absorption by the plant. Stunted plants continued to absorb sodium, potassium, boron and lithium; in fact, in most soils, leaf sodium increased to injurious levels. They suggested that an organic ion-absorption inhibitor is a possible cause of the phenomenon, which lasts from a few weeks to a year or more. Heavy phosphorus applications to the soil and foliage nutrient sprays of copper and zinc give substantial improvement in growth, although lengthening the period between treatment and planting reduces the severity of stunting and sodium toxicity.

In recent investigations, Kleinschmidt and Gerdemann (1972) found that citrus seedlings in sterilized soils grew poorly when no endomycorrhizal fungi were present near the roots. The seedlings made healthy growth, however, when *Endogme mosseae*, an endomycorrhizal fungus was introduced. This suggests a need for innoculation of sterilized soils with these fungi to assure good seedling growth.

In many climates, it is necessary to protect the seedbed and emerging seedlings with some type of shelter. Both intense sun and wind may cause emerging seedlings to burn. Various types of shelters may be used depending upon availability of materials and the size of the seedbed. Wood lath, camouflage netting, hardware cloth, Saran, and cheesecloth are examples of manufactured materials used to provide shade. Suitable shade may also be provided by native cane and prunings (Domato and Aramayo, 1953). Shading should be placed over the seedbed when the soil temperature reaches 90° F and arranged to permit about 50 per cent direct sunlight to fall on the seedbed. When lath or cane is used, it is more effective if it lies in a north-south direction so the shadow will move constantly and evenly. Height of the shade should be sufficient to provide access to the seedlings underneath.

In humid climates, shading is sometimes practiced, but more often seedbeds are unprotected. Camp (1950) noted that under Florida conditions the lath shade has a tendency to increase seedling diseases. Even in arid, hot climates some nurserymen do not construct shade shelters. Instead, they sow barley with their citrus seed, since it germinates earlier and protects emerging citrus seedlings (fig. 1–1).

The size and arrangement of the seedbed varies considerably, depending upon the number of seeds to be planted, the width of tillage equipment, the type of irrigation, and the locality (fig. 1-2). In Florida, many large seedbeds are planted with single rows 6 inches apart or wider, depending on the type of cultivation. In California, seedbed size and arrangement is regulated by the needs of the nurseryman. Often side boards of 1- by 12-inch or 2- by 12-inch lumber are used to define the beds and prevent disease contamination from the walkways (fig. 1–3). Frequently, these beds are enclosed by a framework (fig. 1–4) that supports removable shelter material (lath,

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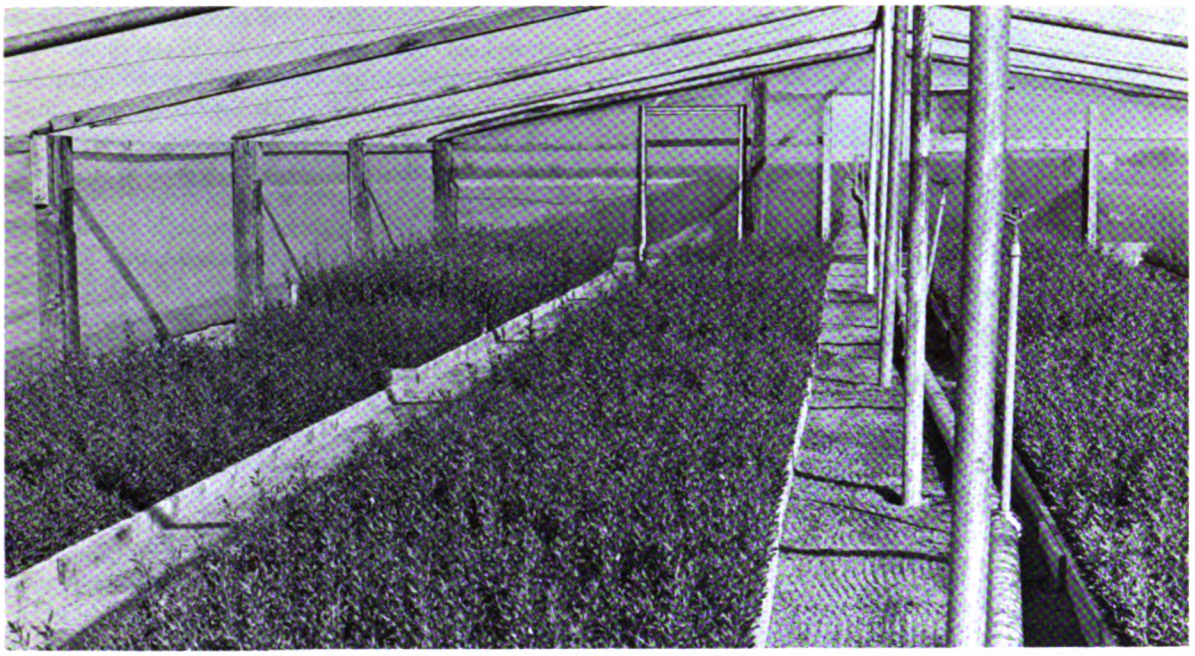

Fig. 1–3. Citrus seedbed showing framework which held Saran cloth shade, now removed. Note sideboards to define the beds and protect seedlings from disease contamination.

Saran, cheesecloth). Where rodents or other small animals are a problem, wire netting is placed around the seedbed area to exclude them.

Some California nurserymen utilize plastic-covered houses for citrus propagation. The seedlings in the seedbed, lined-out seedlings, and budlings are grown within plastic-enclosed structures where temperature for optimum growth at all times can be maintained by heating equipment. Seedbeds in such shelters are either at ground level or are raised to waist level for convenience and as a precaution against contamination.

If the soil is infertile, a soluble chemical fertilizer is usually applied. The kind of fertilizer varies with local requirements. In California, a soluble chemical fertilizer, high in nitrogen, is commonly applied at the rate of 1 pound actual nitrogen per 100 square feet. Application should be made at least one month ahead of planting to prevent damage to young seedling roots.

Whatever the size and arrangement of the seedbed, the soil should be worked to a fine tilth, firmed, and leveled before the seed is planted.

Damping-off of seedlings in the seedbed is caused by several fungi, but principally *Rhizoctonia solani* Kuehn. Weindling and Fawcett (1936) found that damping-off was reduced from 31 to 1.7 per cent by acidifying the soil next to the seed with aluminum sulfate or acid peat moss. Acidification of the soil favors the growth and parasitic activity of the *Trichoderma* fungus which attacks *R. solani*. Other fungi also cause damping-off or seedbed infection. Olson (1954) and Brun (1953) reported *Sclerotinia* spp. as being the cause of damping-off on sour orange seedlings. Brun sug-

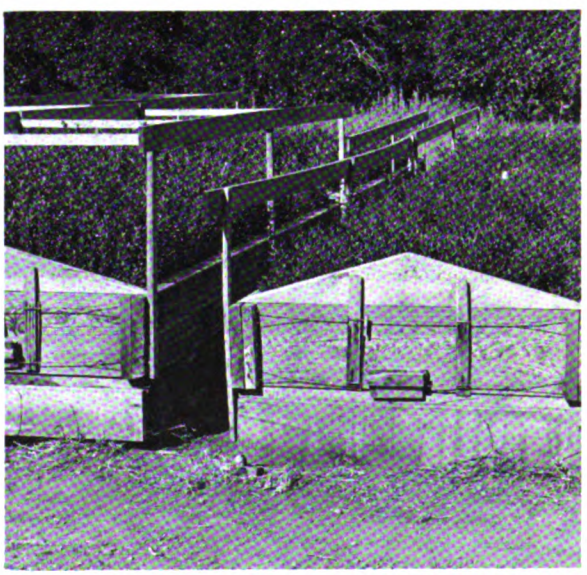

Fig. 1–4. Small seedbeds constructed entirely above ground. The frame above the seedlings held a lath shade while the seedlings were small.

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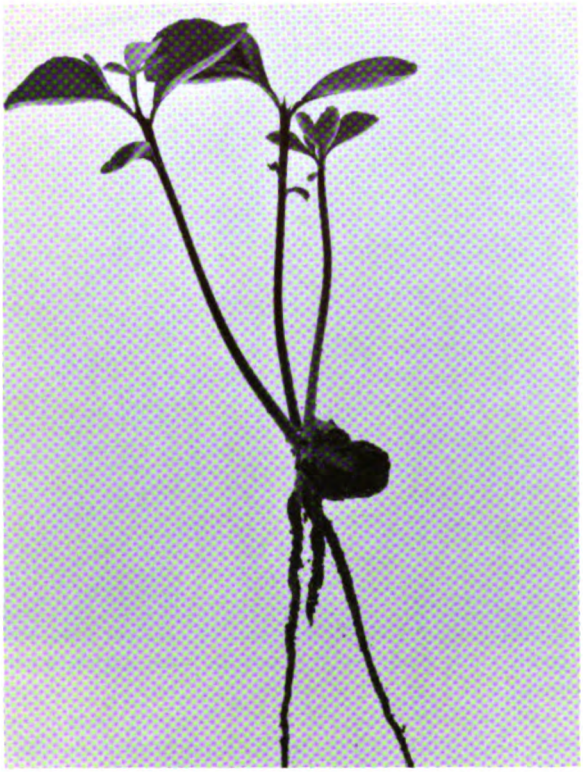

Fig. 1–5. Three seedlings emerging from a single Troyer citrange seed.

gested disinfecting the soil at a depth with 1 per cent of commercial formaldehyde or spraying the surface with 5 to 10 per cent of formaldehyde.

To prevent damping-off, nurserymen in California occasionally sprinkle a solution of Special Semesan (hydroxymercurichlorophenol) on the surface of the seedbed. A dosage rate of 3 ounces in 17 gallons of water will treat 1,000 square feet. After the soil has dried to a depth of two to three inches, the surface is acidified by applying 1¼ ounces of aluminum sulfate per square foot and carefully raking it into the upper inch of soil.

Planting the Seed.—Seeds of most citrus are planted in the spring as soon as the soil warms. In some areas, however, soil temperatures never drop below the critical point for seed germination, and planting may be done whenever the seed is mature.

Citrus seed usually germinates slowly. A soil temperature above 55° F (Webber, 1948*b*) is required for germination. The optimum temperature is between 80° and 90° F. Under normal springtime temperatures, it takes from three to four weeks for seedlings to emerge. If a soil temperature of 80° to 85° F is maintained by using bottom heat, germination occurs in ten days.

In most subtropical citrus regions, planting too early, before the soil is warm enough, may cause seed to rot or seedlings to be damaged by frost or freezing. Seed is planted as early as possible to obtain maximum growth during the season. Late planted seed not only has a shorter season in which to grow, but where seedbeds are not covered or protected by a nurse crop, seedlings may burn as they emerge if soil temperatures are too high.

Most seed is planted by hand. A few nurserymen, however, use mechanical seeding devices. The seed may be scattered over the bed. Excess seeds should be removed where they are too thick and filled in where they are too thin. They should not be spaced closer than 1 inch apart and placing them 1½ to 2 inches apart results in sturdier growth. One way to insure more accurate spacing is to depress the soil slightly with a stick as a guide for spacing the seed.

The bed is then covered with a ¾-inch layer of clean river sand, peat moss, or sphagnum moss. This covering provides a nearly sterile medium through which the seeds may emerge without difficulty and prevents excessive drying and crusting of the soil. If any likelihood exists that the sand is contaminated with fungi or nematodes, it is fumigated. Methyl bromide, chloropicrin, or chlorobromopropane are satisfactory fumigant materials. To prevent seeds from floating out, it is common practice to press the covered seed into the soil by placing a clean board on the sand-covered seed and walking on it.

In Florida, seed is usually sown rather thickly in the bottom of a furrow approximately 1½ inches deep. Often segments of the fruit are placed along the furrow bottom. In either case, the furrow is then filled with the available soil. Another method, said to result in better seedlings, is to plant the seeds individually 1 inch apart in the furrow at a depth of ½ to 1 inch.

The number of seeds to plant in relation to the number of seedlings required is an important consideration. Most rootstock species are polyembryonic and often two or three seedlings grow from one seed (fig. 1–5; see also vol. II, chap. 4). Under ideal conditions and with some citrus, it is possible to obtain more seedlings than seed planted, but this rarely occurs. Some seeds fail to germinate. Weak, crooked-rooted seedlings and variant seedlings are discarded. From a practical standpoint, therefore, twice as many seeds

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should be planted as the number of seedlings required.

Seedbed Cultural Practices.—In most climates, proper irrigation of the seedbed is one of the most critical aspects of successful seedling growth. The soil surrounding the germinating seed must not dry out, yet it must not be kept so saturated as to rot the seed or cause disease problems. Germinating seeds are quickly killed by drought. On the other hand, excessive moisture favors development of the principal damping-off fungus species of *Rhizoctonia*, as well as species of *Phytophthora*, and *Sclerotinia*.

The frequency of irrigation depends on the soil, climate, rainfall, and size of the seedlings. Frequent, light watering is required for newly planted seedbeds until seedlings reach a height of 3 to 4 inches. From this point on, less frequent, larger applications of water are needed to maintain maximum growth.

Water may be applied by any convenient method, so long as the amount can be controlled. Tensiometers, placed in the zone of root activity after the seedlings emerge, help determine when to irrigate (fig. 1–6).

The need for fertilization depends upon the fertility of the seedbed soil. Where the addition of plant food is indicated, it is lightly applied as required during the season. Nitrogen is the most commonly deficient element, although in some areas phosphorus and potash are also deficient. One pound of chemical nitrogenous fertilizer per 100 square feet of seedbed is the normal application rate in California. This may be in the form of low biuret urea, ammonium sulfate, ammonium nitrate, or calcium nitrate. Low biuret urea may also be applied as a spray to the foliage at 7½ pounds per 100 gallons of water. In Florida and other areas of less naturally fertile soils, heavier fertilization is generally required. An application of 4-7-5 (NPK) mixed fertilizer at 200 to 500 pounds per acre is used when seedlings are 1 to 1½ inches tall. Applications are made at intervals of three to four weeks, and the amount is increased to a maximum of 500 to 1,000 pounds per acre when seedlings are twelve months old. After seedbed soil has been fumigated, it may also be necessary to treat for zinc, copper, and phosphorus deficiency. (See "Preparation of Seedbed," p. 5.) When chemical fertilizers are applied to the soil, any chemical residue remaining on the seedlings must be washed or brushed off to prevent burning the leaves.

Insects and mites should never be allowed to build up to damaging populations. Under seedbed conditions, the buildup can be so rapid that it is not possible to rely upon biological control. Treatment to control pests should be started as soon as they appear.

All weeds are removed before they compete with the seedlings for light, moisture, and nutrients. Perennial noxious weeds are best exterminated in nursery soils before planting seed.

In colder climates, where frosts or freezes occur, seedbed protection is necessary. For light frosts, a cover is effective in preventing heat losses by radiation. Orchard heaters, placed around and through the seedbed and shielded to prevent the seedlings from being scorched, are effective for more severe cold. Seedlings grown in a glasshouse or enclosed polyethylene shelter may be protected with various types of heaters. If unvented gas or petroleum heaters are used, however, the structure must be ventilated to prevent the accumulation of gases toxic to the seedlings. Successful protection against freeze damage has been reported in Florida through the use of water sprinklers on large seedbeds (Dean, 1963; Gerber and Hendershott, 1963). This method has not proven satisfactory in California; however, under some seedbed arrangements, where flooding is used for irrigation, running water has given some benefit. When using this type of protection, a sandy soil capable of good water drainage is

Fig. 1–6. Tensiometer placed in rooting area of seedbed soil provides a guide to proper moisture control. Note Saran cloth shade to protect seedlings from direct sun.

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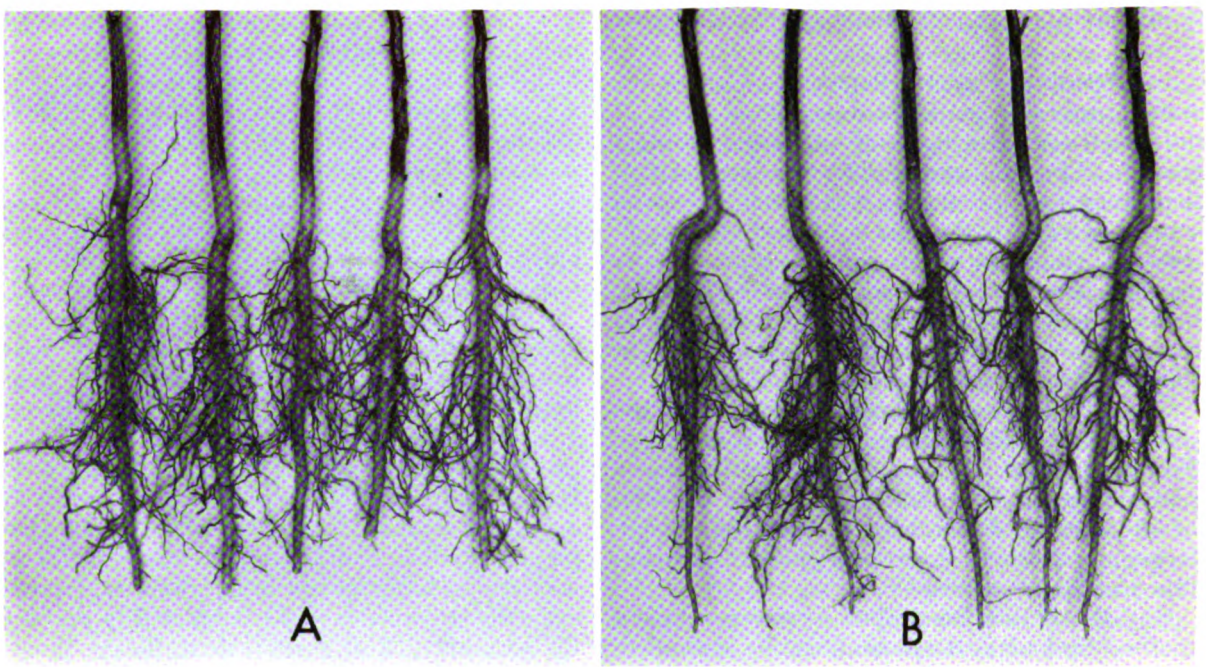

Fig. 1–7. Citrus seedlings with *A*, straight; or *B*, slightly bent roots, are satisfactory for transplanting.

needed to avoid waterlogging and damage to the seedlings.

Disease control is usually accomplished by employing the sanitary practices discussed earlier in connection with seed treatment and seedbed preparation. In spite of all precautions, however, diseases sometimes occur. Prolonged wet soil, high humidity, excessive shading, and overcrowding are conducive to fungus growth. Should the brown-rot fungus, *Phytophtora*, invade the seedbed, healthy seedlings can be protected by spraying the entire bed with a Bordeaux mixture of 3 pounds of zinc sulfate, 2 pounds of copper sulfate, and 6 pounds of hydrated lime per 100 gallons of water or 1 pound of active Captan ingredient per 100 gallons of water. The diseased seedlings should be removed and destroyed (Klotz *et al.*, 1966). In areas where scab and anthracnose attack susceptible seedlings, a tri-basic copper fungicide is suggested when seedlings are six to eight weeks old. This should be followed with copper, zinc, or mercury carbamates at monthly intervals.

Digging the Seedlings.—Seedlings are dug from the seedbed just before they are transplanted in the nursery. The stems are usually $\frac{3}{16}$ to $\frac{1}{4}$ inch in diameter an inch above soil level and from 8 to 24 inches high depending on the species, length of time in the bed, and conditions under which they were grown. Well-grown seedlings in areas of continuous growth may reach transplanting size in six months, although a year is generally required. Some slow-growing species may take two years to reach adequate size.

Moist seedbed soil is required to avoid root losses in digging. Seedlings are lifted with a long-tined spading fork and carefully pulled from the bed by hand. Care is taken to keep root damage to a minimum. With large, vigorous seedlings, it may be necessary to use a spade to cut the taproot about 8 to 10 inches below the surface.

After removal from the seedbed, the seedlings are culled and those with diseased, crooked, or deformed roots are discarded. The extent of seedling root deformity that may be tolerated without harmful effect on the subsequent growth and production of the orchard tree has long been a question. There is no evidence that moderate bench roots affect vigor and production (fig. 1–7), although it is likely that severe deformities, such as complete curl or a doubling back of the taproot, have an effect on growth (fig. 1–8). Observations made by the authors indicate that under some conditions severe benchrooting or curling is detrimental to tree growth. It is good practice, therefore, to discard such seedlings.

Those seedlings markedly smaller than average are eliminated. While small seedlings may result from late germinating seed, it is likely

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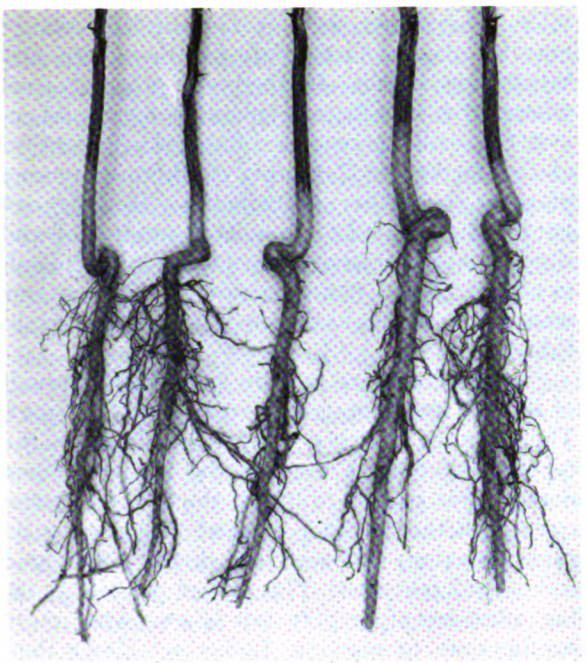

Fig. 1–8. Seedlings having severe bench root (complete curls or doubling back) should be discarded.

they are gametic and, therefore, different from the seed parent. In addition, seedlings markedly larger than average or showing abnormal foliage characteristics are discarded. These too are likely to be gametic seedlings and their performance as rootstocks is uncertain. It is false economy to try to use every seedling: only the best are saved for transplanting.

Even the best seedbeds produce nucellar seedlings of variable size. To obtain more uniformity in the nursery, it is desirable to segregate seedlings into three or more uniform groups. The larger seedlings usually attain budding size sooner and make larger nursery trees. Root systems too large for the transplant hole are cut. The tops also are cut back to balance the loss of the roots.

Seedlings are planted as soon as possible after digging. In the interval between digging and planting, the roots must be protected from sun, wind, and heat at all times. This is particularly important in the more arid citrus regions. Damp burlap or shavings uncontaminated by fungi will provide such protection. Immersing the roots in water for more than a few minutes is a risky practice and should be avoided.

If the seedlings are to be shipped or stored, the roots are packed in a suitable moisture-retaining material such as damp sphagnum or peat moss. They are stored in the shade with adequate atmospheric humidity provided.

The Nursery

In most cases, seedlings are transplanted in an intensively cultivated area of a nursery, where they are grown, budded, and formed into standard nursery trees. The necessary care and training to assure high grade trees is most easily accomplished if the nursery is in a concentrated area where a population of approximately 10,000 trees per acre is customary.

It is possible to transplant seedlings directly to the orchard, and some growers do this in the belief they will have an orchard tree in less time. This practice is not generally recommended since adequate irrigation, weed control, and pest control can seldom be achieved for seedlings and budlings grown in an orchard setting. The loss of a seedling or a budding failure in an orchard location is much more serious than in the nursery.

Selection of Site.—The nursery is best located in a warm area where the frost hazard is minimal and soil and water conditions are favorable. A medium-textured, deep, uniform soil is desirable. Clay soils should be avoided. They prevent good feeder root development and make balling difficult. Sandy soils require more frequent fertilization and irrigation, but produce good trees with a large number of feeder roots. Regardless of texture, nursery soils should be free from accumulations of injurious salts, stones, and trash. It is also important if nursery trees are to be balled that the nursery soil be as nearly like that of the orchard soil as possible.

In windy areas, windbreaks are necessary. They are usually essential in coastal areas where cool or chilling winds off the ocean materially reduce the growth rate of seedlings and buds. If natural windbreaks (eucalyptus, cypress, etc.) are used, they should be established before planting the nursery. Competition from windbreak tree roots is avoided by root pruning, and tall windbreak trees are trimmed to prevent shading of the nursery.

The practice of growing nursery stock between the rows of young orchard trees is unsatisfactory. Since nursery trees require special attention, site layout should be designed to facilitate cultural operations and digging without the hindrance of an orchard layout. Although orchard trees may appear to shelter young nursery stock,

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growth of the older trees competes with the smaller trees. Also, there is considerable risk to nursery trees from contamination by nematodes, insect pests, and disease.

Soil Preparation.—Comments concerning the selection and treatment of seedbed soil also apply to nursery soil. Soil virgin to citrus is the first choice. If old citrus soil must be used, it should be treated with a soil fumigant before planting the seedlings.

Some nurserymen fumigate nursery soil regardless of its past history. This is done as an added precaution against possible contamination by soil-borne pests or diseases. It also is effective in weed control.

To assure proper and uniform irrigation, the soil is deeply tilled and leveled to grade. On soils low in fertility, legume cover crops are beneficial for two or three years prior to planting the nursery. Such soils usually require the addition of chemical fertilizers, which are applied when the cover crop is worked into the soil several weeks before planting the seedlings.

Planting the Seedlings.—In areas where frosts occur, seedlings (called "liners" when set out in rows in the nursery) are planted in early spring as soon as frost danger is past. Some cold-tolerant seedlings such as the trifoliate orange may be planted in the late fall or winter with satisfactory results. In the more tropical areas where frost is unknown, planting occurs whenever the seedlings reach a suitable size, regardless of season. Under California conditions, summer planting is usually unsatisfactory. Seedlings set out in summer tend to grow later into the fall and show greater sensitivity to cold. It is also difficult to obtain a good stand because of more extreme weather conditions as the seedlings become established.

Seedlings are usually spaced at intervals of 10 to 12 inches in straight rows 3 to 5 feet apart. The distance between rows depends upon the type of equipment used in the nursery. Some nurserymen prefer to plant double, staggered rows with the seedlings spaced 12 inches apart each direction, and with the double, staggered rows 4 to 5 feet apart. This system permits planting more trees per acre but is somewhat more troublesome to manage. Liners set closer than 10 inches apart do not grow as large, and where trees are balled, the balling operation is made more difficult and the trees are too close to form adequate size balls. Japanese nurserymen, however, space liners every 4 inches in rows 6 to 7

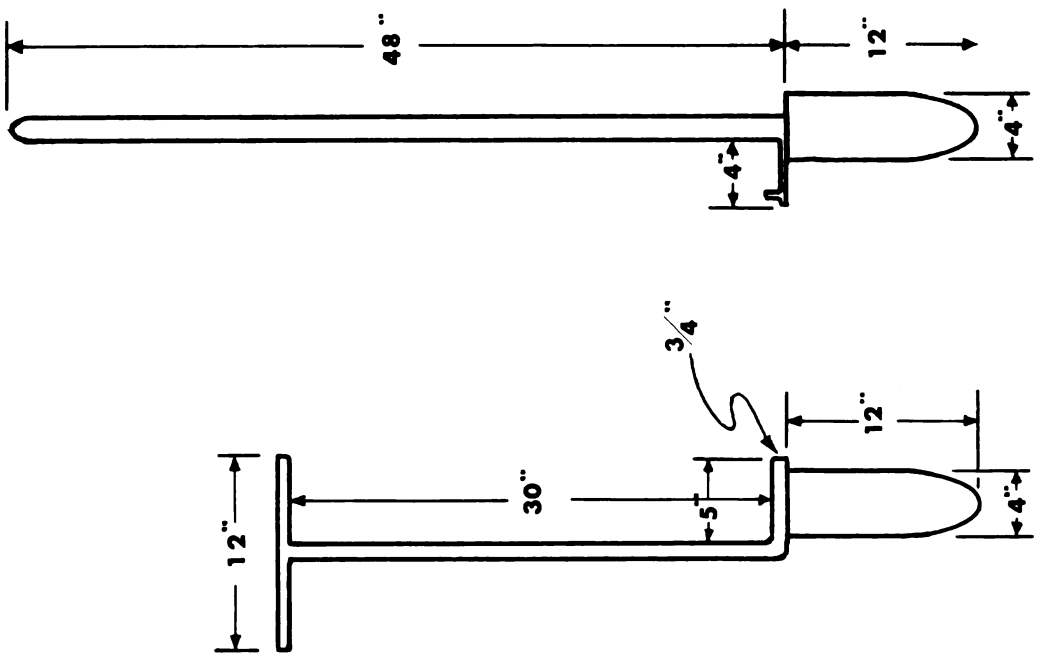

Fig. 1–9. Two types of dibbles used to make holes for seedlings, and to firm soil around roots after planting.

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inches apart, with approximately 2 feet between double rows (Bitters, 1964). Under such conditions, this is practical, since the trees (largely satsuma mandarin) are smaller and barerooted for orchard planting.

If furrows are used for irrigation, row length is determined by the requirements for uniform and adequate water penetration. Long, narrow nursery blocks are difficult to protect against frost. In most citrus areas of the world, it does not matter which direction the rows run in relation to sunlight. If strong prevailing winds blow from one direction, however, it is easier to train budshoots in rows that run parallel with the prevailing wind.

Liners are usually planted with the aid of a dibble (fig. 1–9). The planting hole must be large enough to accommodate all roots easily and allow the seedling to stand at the same height it grew in the seedbed. It is important that roots not be forced into the dibble hole, since they will bend, grow crooked, and reduce normal tree growth. It is also important to avoid air pockets in the planting hole and to assure firm contact of seedling roots with soil. This may be accomplished by thrusting the dibble into the ground at an angle, with the point 3 to 4 inches away from the liner and parallel to the planting hole. When the dibble bar is straightened perpendicularly, it firms the soil about the roots.

Some nurserymen plant liners by forming a furrow of sufficient depth to accommodate the roots without bending. They then set the liner against one side of the furrow and firm the soil around it. Regardless of the planting method, a thorough irrigation follows in order to settle the soil around the roots and provide ample moisture for plant growth.

The manner in which seedlings are planted in regard to irrigation varies with locality and conditions. One method is to plant the seedlings in unfurrowed soil, then form narrow, shallow furrows for irrigation on either side of the row.

A second method is to first form a permanent, broad furrow, 12 to 15 inches wide, then plant the seedlings in the furrow bottom (fig. 1–10). This method is of particular advantage in areas where the accumulation of salts from the soil or water is apt to occur. By running water in the furrow bottoms where the seedlings are planted, the concentration of salts in the area of rooting is kept to a minimum. Roots develop well under such a system, and, with proper precau-

Fig. 1–10. Double row of seedlings planted in bottom of broad permanent furrow.

Fig. 1–11. Seedlings planted on flat soil with no furrows. Irrigation is by sprinklers.

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tions, gummosis (*Phytophthora* spp.) is not a problem.

A third method is to plant the seedlings on flat soil, without forming furrows, and irrigate with sprinklers (fig. 1–11). This method requires the use of water low in total salts and nearly free of toxic elements such as sodium, chloride, and boron. Use of low-salt water is particularly necessary in arid climates. Sandy soils are preferred for sprinkler irrigation, since water infiltration is rapid. On medium or fine-textured soils, sprinkler irrigation may result in excessive water runoff or erosion unless a mulch is provided.

Seedling Care in the Nursery.—The rate of seedling growth in the nursery is largely determined by maintaining an adequate supply of soil moisture at all times. Provisions should be made for irrigation when rainfall is insufficient. In California and Arizona, irrigation must be provided. In most other citrus-growing regions, irrigation is necessary during periods of drought. In Florida, for example, it is recommended that one to two inches of water be applied each week during the growing season if rainfall is inadequate.

Overirrigation causes seedlings to grow poorly and become pale or yellow in color. On the other hand, lack of water stunts growth and prevents buds from uniting with the stock. Trees too wet or too dry are also more subject to frost damage. The method of applying water is determined by the soil, terrain, available irrigation systems, and preference of the nurseryman (see chap. 8).

Young citrus trees require relatively large amounts of plant food high in nitrogen. To maintain satisfactory growth, fertilization is generally necessary. Fertilizer is applied in light but frequent amounts. In California, the common practice is to apply 1 pound of nitrogenous chemical fertilizer per 100 feet of row as often as necessary to maintain good tree growth. In Florida, an application of 50 pounds of 4–7–5 (NPK) mixed fertilizer per 1,000 seedlings is made every three to four weeks. This amount is increased to 75 to 100 pounds after the seedlings are three months old. Organic sources, free of toxic salts and weed seeds, are sometimes used if the soil tends to leach. In areas subject to winter cold, it is desirable to withhold fertilization after midsummer so the trees will harden and better withstand low winter temperatures.

After application of concentrated fertilizers, the soil is thoroughly wet to distribute the material evenly throughout the root zone. A light rain or irrigation following fertilization may result in a serious burn because of toxic amounts of fertilizer accumulating around the roots.

Micronutrient element deficiencies often occur in fast-growing nursery trees. In California, zinc and manganese are frequently deficient, and in some sections copper and iron are lacking. Corrective measures are taken as these deficiencies occur.

Weed control is accomplished primarily by cultivation, hoeing, or chemicals. It is important that weeds be eliminated to prevent competition with the nursery trees. Noxious weeds must be eradicated before the trees are balled and preferably before the seedlings are lined out. Other pests such as insects, mites, and rodents must be controlled. In fact, every effort must be made to keep the seedlings growing vigorously by eliminating all competition to the nursery trees.

The growth of nursery trees in coastal and other locations is often slower than desired because of a cool climate. Cahoon *et al.* (1963) showed that, under such climatic conditions, the use of plastic ground covers to raise soil temperatures significantly increased scion growth of nursery trees on sweet orange and Cleopatra mandarin rootstock. Growth increases were not obtained, however, for scions on Troyer citrange rootstock in coastal areas nor on Troyer citrange or trifoliate orange rootstock in warmer, inland areas. While both clear and black polyethylene and vinyl materials resulted in higher soil temperatures, the black plastic had the added advantage of providing weed control.

To develop a clear, straight trunk suitable for budding seedlings, it is necessary to remove the suckers or small branches on the seedling up to and slightly above the height at which the bud is placed. Some California nurserymen have recently adopted the practice of slipping an 8- to 10-inch paper, foil, or plastic tube over the seedlings as they are lined out or soon after planting (Halsey, 1966). (See figs. 1–12 and 1–13.) This prevents suckers from growing below and at the point of budding and eliminates much tedious labor. As previously mentioned, some species of citrus seedlings such as sweet orange and grapefruit tend toward bushy growth and require more training and suckering than do such species or varieties as Troyer citrange, rough lemon, sour orange, and Cleopatra mandarin. Where high budding is practiced, it is often necessary to grow seedlings two years in the nursery to get a straight,

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unbranched trunk of sufficient height. With bushy-growing varieties such as sweet orange, a straight trunk may be obtained by lopping the seedling after it reaches a height of 18 to 24 inches. A strong shoot from a single vigorous bud originating below the lop is then chosen as the stem for budding and grown to the desired height.

The final suckering and trimming is done at least three weeks before budding or on the day the buds are placed in the seedlings. Pruning or sucker removal during the three-week period before budding tightens the bark, makes budding difficult, and lessens the chances for a good bud take.

The height of budding varies greatly in the different citrus areas of the world. In most cases, there are valid reasons for the height chosen. In Florida, for example, low budding at 2 to 3 inches above the soil is the standard practice. Trees so budded may be more easily banked with earth for frost protection. At the other extreme is high budding, 20 to 36 inches, which is practiced in Sicily as a preventive measure against infection of the scion with soil-borne fungi such as *Phytophthora* spp. and *Dothiorella* sp.

There are other instances where high budding is advantageous. In California, many lemon trees are propagated with buds placed at a height of 20 to 30 inches. This replaces the lemon trunk with the rootstock species and eliminates deterioration of the trunk by shell bark (decorticosis) and dry bark (siccortosis), maladies to which many lemon selections are susceptible.

Where soil-borne fungus infection is probable on susceptible scions, buds are placed high enough to take advantage of rootstock resistance to these fungi. Six to eight inches above the soil is a minimum bud height under such conditions. Many California nurserymen, in fact, consider 8 to 10 inches the minimum height for budding.

Budding the Seedling.—Perhaps the single most important step in producing a first-grade nursery tree is budwood selection. Recognition of this fact is indicated by the establishment of bud-

Fig. 1–12. Plastic tubes slipped over seedling trunk to reduce labor of suckering and produce a straight trunk.

Fig. 1–13. Aluminum-foil tubes around seedling trunks reduce suckering.

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wood selection, registration, or certification programs in the major citrus areas of the world (Allen and Carpenter, 1966; Allen and Streets, 1961; Beñatena and Pujol, 1965; Mather, 1963; Anonymous, 1962; Nauer *et al.*, 1967; Norman, 1959; Rossetti *et al.*, 1963; Sleeth, 1959).

Selection of budwood.—The primary emphasis of budwood selection programs is placed on the use of virus-free budwood sources. In most cases, nucellar clones are virus-free; however, contamination by virus diseases has resulted from root grafts, careless propagation, and, in some cases, insect vectors and mechanical transmission. With the increasing use in many areas of trifoliate orange, trifoliate orange hybrids, and Rangpur lime as rootstocks, care must be taken that budsource trees are not carriers of the exocortis virus on symptomless rootstocks (Opitz, 1960). The same precautions are necessary for other virus diseases which damage only certain rootstock-scion combinations. With regard to exocortis, it is important that budding knives and pruning shears be sterilized after use on exocortis-infected plant material since this virus can be mechanically transmitted on contaminated tools (Garnsey and Jones, 1967).

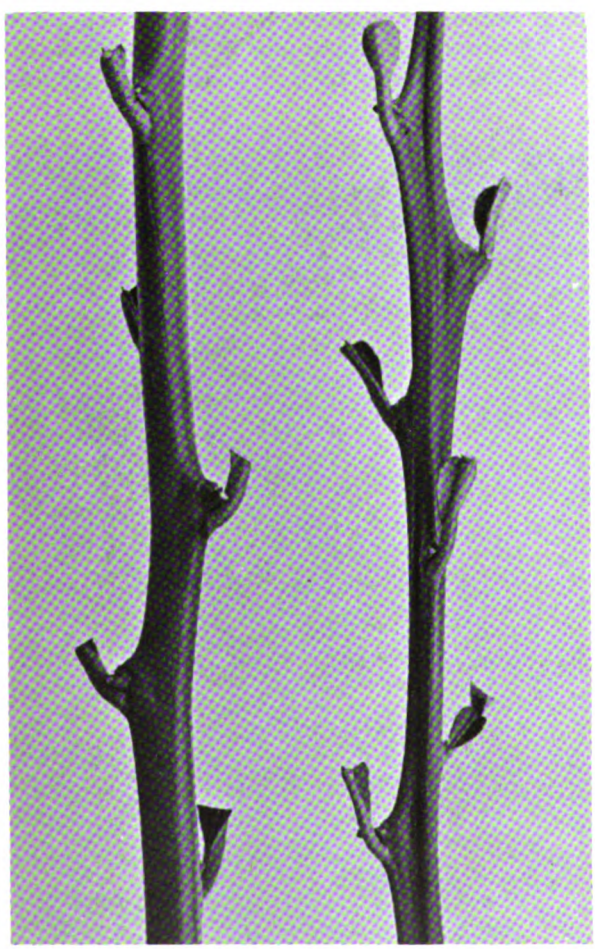

Fig. 1–14. Types of citrus budwood. *Left*, round, hardened twig is usually preferred. *Right*, angular, less-mature twig may be used.

It is also important to make certain budwood comes from trees known to be true-to-type and capable of high yields in the areas where they are to be planted. The tendency of citrus trees to produce variants is well known (Soost *et al.*, 1961). (See also vol. *II*, chap. *4*.) Every precaution should be taken to avoid the use of buds from trees or branches which show any variation from normal. Careful observation and performance records are essential in successful budwood selection.

Nurserymen express some differences of opinion as to which type of wood provides the best buds. In practice, however, there appears to be considerable latitude in the size and age of budwood that gives satisfactory results. Generally, the most satisfactory buds are obtained from budsticks taken from vigorous shoots of the next to last growth flush, or from the last flush after the growth hardens. Very often, good buds may be obtained from older growth flushes if the bark is still green. Round twigs are preferred, but budsticks cut from angular, less mature twigs have provided satisfactory buds (fig. 1–14). In fact, some Florida nurserymen prefer the angular budwood. Regardless of budwood shape, the buds should be dormant and well developed. Buds in the axils of large leaves are less apt to remain dormant in the stock. Small buds in the axils of small leaves usually start slower.

Halma (1933) compared the growth of buds from the apical and basal halves of the same budstick and from different cycles of growth developed during the same year. He found no difference in size of one-year-old Valencia orange trees produced from these buds. Halma also compared the size of year-old Valencia orange trees produced from buds cut from budsticks ranging from 3 to 11 millimeters in diameter. Again, no significant differences were found.

The satisfactory use of small buds cut from small twigs is described by Wishart (1961) in Australia. This technique, termed "microbudding," allows many more buds to be cut from a single bud-source tree and permits the use of much smaller seedling rootstocks. It also permits the use of angular budwood of small diameter.

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In older bud-source trees that have matured and produced fruit for several years, the position on the tree from which budwood is taken is of little consequence. On the other hand, where young trees, particularly nucellar clones, are used for budwood sources, the position from which buds are cut influences thorniness and the age at which the tree begins to bear.

Frost (1948) demonstrated in several trials that thorny budwood from young seedling clones produced thorny nursery trees, but that if thornless budwood was selected, the progeny trees were also thornless or nearly so. He further demonstrated that trees produced from thornless budwood came into production at an earlier age. Several investigators, including Frost (1948), Cameron, Soost, and Frost (1959), and Furr (1961) have shown that on young vigorous trees, buds taken high in the tree produce progeny that are more precocious than those produced from buds taken from the basal portion of the tree.

Storage of budwood.—At the time of cutting, all leaves and thorns are clipped off the budsticks, which are then cut in convenient lengths. For the ease in handling, most nurserymen tie the sticks in small bundles and label them with the date, name, and source. At no time should budwood be allowed to dry out.

Most budwood is used within a few days after cutting. If necessary, the budsticks may be held for two or three months by placing them in damp peat moss, coarse sawdust, or vermiculite, and storing them in boxes or folded, damp, burlap sacks in a cool, dark area. Care must be taken, even for short-term storage, that the storage material be damp, not wet, as molds and fungus may develop rapidly.

A recent, successful method of storing budwood is to place the sticks in sealed polyethylene bags and hold them at refrigerated temperatures of 35° to 45° F. No moisture is added to the bags because there will be sufficient moisture in the budwood itself to maintain it in good condition. In approximately two weeks, the petiole stubs will have abscised from the budsticks. These are removed, since they may start to mold. Thereafter, visual inspection is made periodically, and any decaying budsticks are removed. Moore (1961) reports satisfactory storage for six months by this method, and some varieties have been stored for a year.

Budding process.—Citrus may be budded when the lined-out seedlings reach a suitable size and the cambium is active, causing the bark to slip. In many subtropical regions, seedlings lined out in the spring are large enough to bud in the fall. If they do not attain sufficient size by fall, they are budded the following spring. Most propagators prefer at least pencil-sized stock because smaller seedlings are too limber to handle easily and do not force continuous and vigorous bud growth. On the other hand, buds placed in seedlings larger than ½ inch in diameter at the point of budding do not "take" as readily, nor does the seedling force the bud as easily.

Fall budding in California is usually done in late September and early October, whereas in Florida late October and early November is the normal time. These months are early enough to assure sufficient cambial activity so that the bud unites with the stock, but late enough so that growth does not start. It is the opinion of many nurserymen that fall-budded seedlings tend to produce larger nursery trees and have smoother unions; however, excellent trees are produced from spring buds. Spring budding begins as soon as the bark slips and is preferred by some nurserymen since it eliminates the necessity of carrying budded trees through two winters.

In some areas, summer budding is also practiced. Summer buds however, are often more subject to winter cold damage. They do not have time to achieve adequate growth before the cold

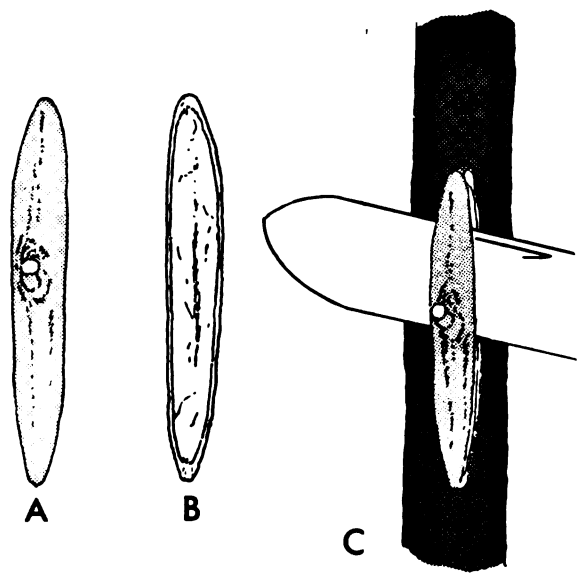

Fig. 1–15. Cutting the bud. *A*, upper side of bud; *B*, underside of bud showing bark and thin layer of wood; *C*, cutting the bud from the budstick.

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weather comes and are, therefore, more tender. In areas where there is no frost, budding may be done at any time of the year when cambial activity permits bud insertion.

The most common method of budding is the shield or eye method (see figs. 1–15 and 1–16). This is also known as the T or inverted-T (⊥) method. Skilled budders use a sharp budding knife with a rounded point. With the knife, they slice a bud with a shield-shaped piece of bark from ½ to 1 inch in length from the budstick. The bud so cut generally includes a thin sliver of wood on the cut side. A sharp knife is essential in making a smooth, clean cut on the base of the bud shield. To correctly position the bud for insertion, the budstick is held upside down for T budding and right side up for inverted-T (⊥) budding (fig. 1–17, *A*).

Holding the cut bud between the thumb and knife blade, the budder makes a 1½ inch long vertical cut through the bark to the wood on the stem of the seedling. Then, with the knife blade held at an angle, he makes a horizontal cut at the upper end of the vertical cut to form a T or at the lower end to form an inverted T (⊥). This opens the bark so the bud may be inserted at the junction of the two cuts (fig. 1–17, *B*). He uses care to place the bud shield so that the bud faces upward.

Another budding method which recently has gained some popularity with Florida nurserymen is known as the "hanging bud." In this method (fig. 1–18), a section of bark, approximately the size of the bud, is cut from the seedling trunk. A "lip" is formed at the upper end of the cut to hold the bud in place. A shield bud is cut as previously described, but the top of the shield is tapered sharply by cutting off the front surface. The tapered cut is inserted under the "lip" of the stock.

Variations of the standard shield-bud method sometimes are employed under special circumstances. In cases where only angular budwood is available, successful budding may be accomplished by side budding (fig. 1–19). In this method, the bud shield is cut so that the bud or eye lies at one side of the shield. It then is in-

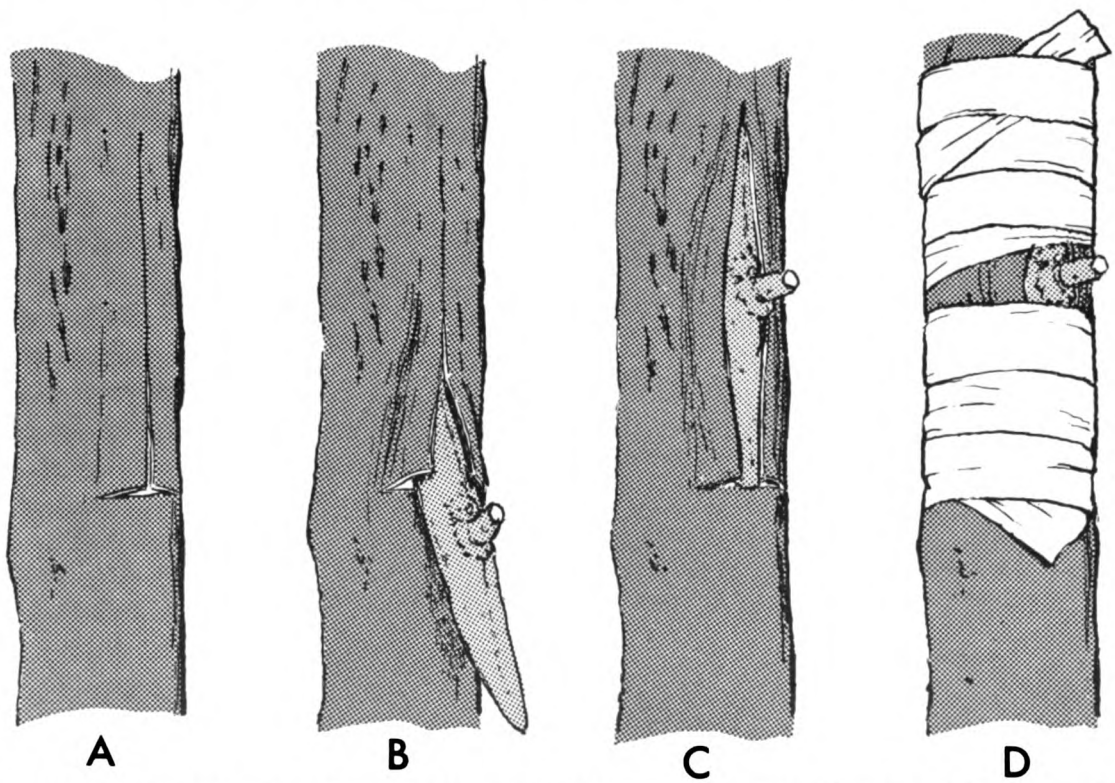

Fig. 1–16. Budding by inverted-T (⊥) method. *A*, vertical and horizontal cuts made through bark of seedling; *B*, bud partly inserted; *C*, bud completely inserted ready for wrapping; *D*, bud wrapped. Bud is left exposed in spring budding and covered in fall budding.

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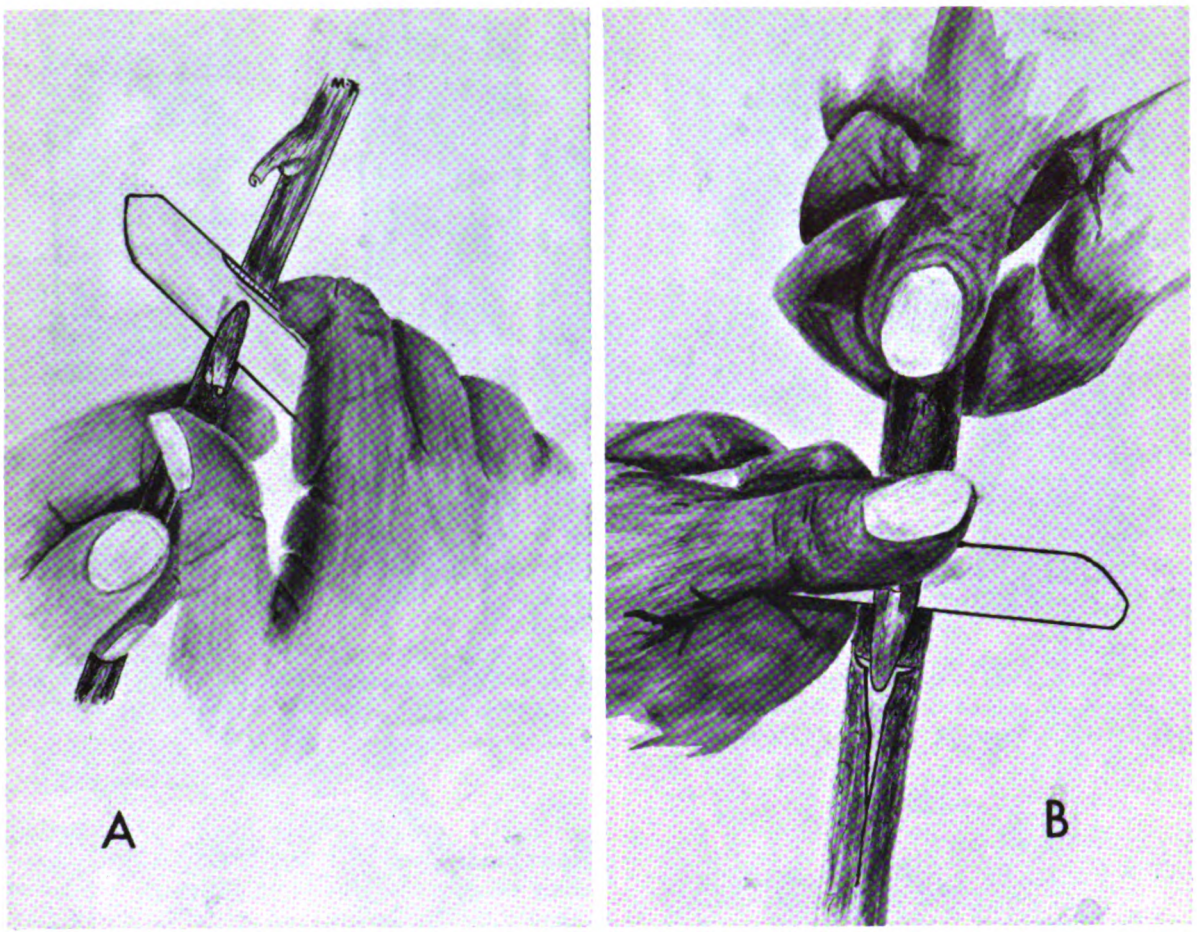

Fig. 1–17. Budding by the vertical-T method. *A*, cutting the bud with budstick held upside down; *B*, inserting the bud by pushing it down into the vertical-T cut in the seedling. Bud is wrapped as in figure 16, *D*.

serted under the bark of the stock on one side of a T or inverted-T (⊥) incision, curved incision, or angular incision.

Mention already has been made of the "microbudding" techniques described by Wishart (1961). The steps involved in this technique are essentially the same as those used for the standard shield-bud method. In cutting the microbuds, however, there are important differences. Budsticks are cut from matured wood with well-developed buds. The leaves are trimmed off, retaining a portion of the petiole (fig. 20, *A*). When cutting the buds the petiole is trimmed off flush with the bud (fig. 20, *B*) and, holding the knife flat, the buds are cut from the budstick, taking a very small sliver of wood (fig. 20, *C* and 20, *D*).

An inverted-T (⊥) cut is made on the seedling stock. The microbud is placed, bud up, under the raised flaps, and pushed firmly to the top of the ⊥ with the thumbnail or bone handle of the budding knife (fig. 20, *E* and 20, *F*). The cambium of the stock must be active so the bark slips freely. Polyvinyl chloride tape is used to tie the bud, starting at the bottom to insure a firm contact between the bud and stock. The tape must cover the bud to prevent drying. The tape is removed after ten to fourteen days for spring buds and in three weeks for autumn buds.

Wishart (1961) suggested complete removal of the stock just above the bud to force bud growth. This is done when the wrap is removed for spring buds, and in the spring following budding for autumn buds. Although the authors do not know of comparative trials with microbudding, it would seem as if bending or better, results if experience with conventional lopping the seedling would give as good, if not buds in California is any criteria (Platt, 1967).

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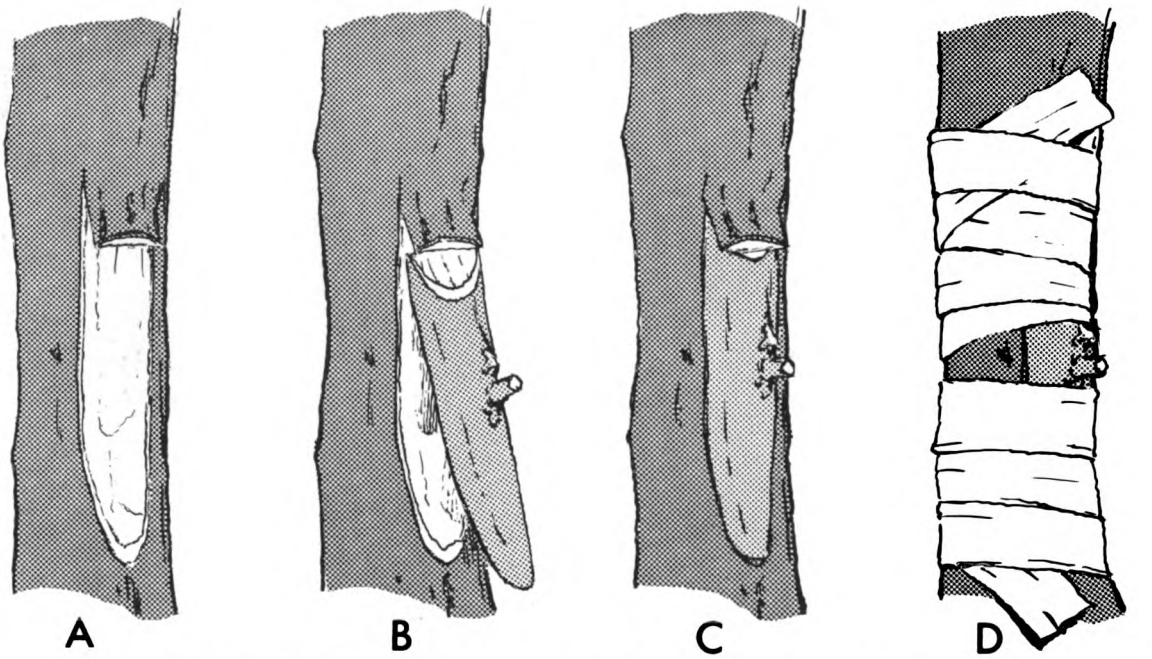

Fig. 1–18. Budding by the hanging-bud method. *A*, shows the section of bark removed from the seedling trunk with "lip" formed at upper end of cut; *B*, shield bud, with upper front surface sharply tapered to fit under "lip"; *C*, bud in place, ready for wrapping; *D*, wrapped bud.

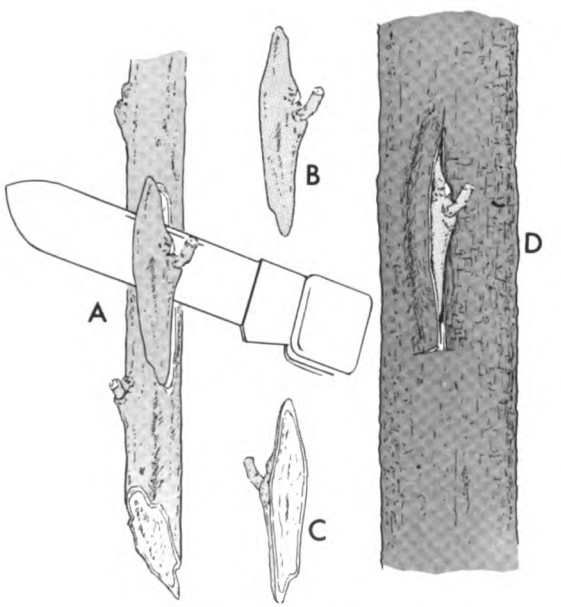

Fig. 1–19. Side-budding, a variation of shield-budding, using buds from angular wood. *A*, cutting the bud; *B*, upper side of cut bud; *C*, under side of cut bud; *D*, bud inserted under one side of inverted-T (⊥) cut in stock.

Of interest are the methods of handling microbuds described by Wishart (1961). They may be cut before budding, although not earlier than the night before, and stored in closed glass containers under refrigeration to prevent drying. When budding, up to one hundred buds may be held in the budder's mouth, larger buds under one lip, and smaller ones under the other. This keeps the buds moist and ready for use on seedlings of different size.

Some workers have questioned the advisability of leaving a wood sliver on the cut surface of the bud. Maiti, Singh, and Singh (1959) reported a significantly greater success in bud take when the wood sliver was removed. In South Australia, Botham (1957) commented that removing the wood is optional, but "gives a greater knitting surface with the stock and is useful when

Fig. 1–20 (page 21). Microbudding operation. *A*, comparison of conventional budsticks (left) and microbud budsticks (right); *B*, cutting petiole off flush with the bud; *C*, cutting the microbud; *D;* microbuds cut and ready for insertion; *E*, microbud pushed under flaps of inverted T (⊥) cut in stock; *F*, microbud pushed secure up into stock, ready for wrapping.

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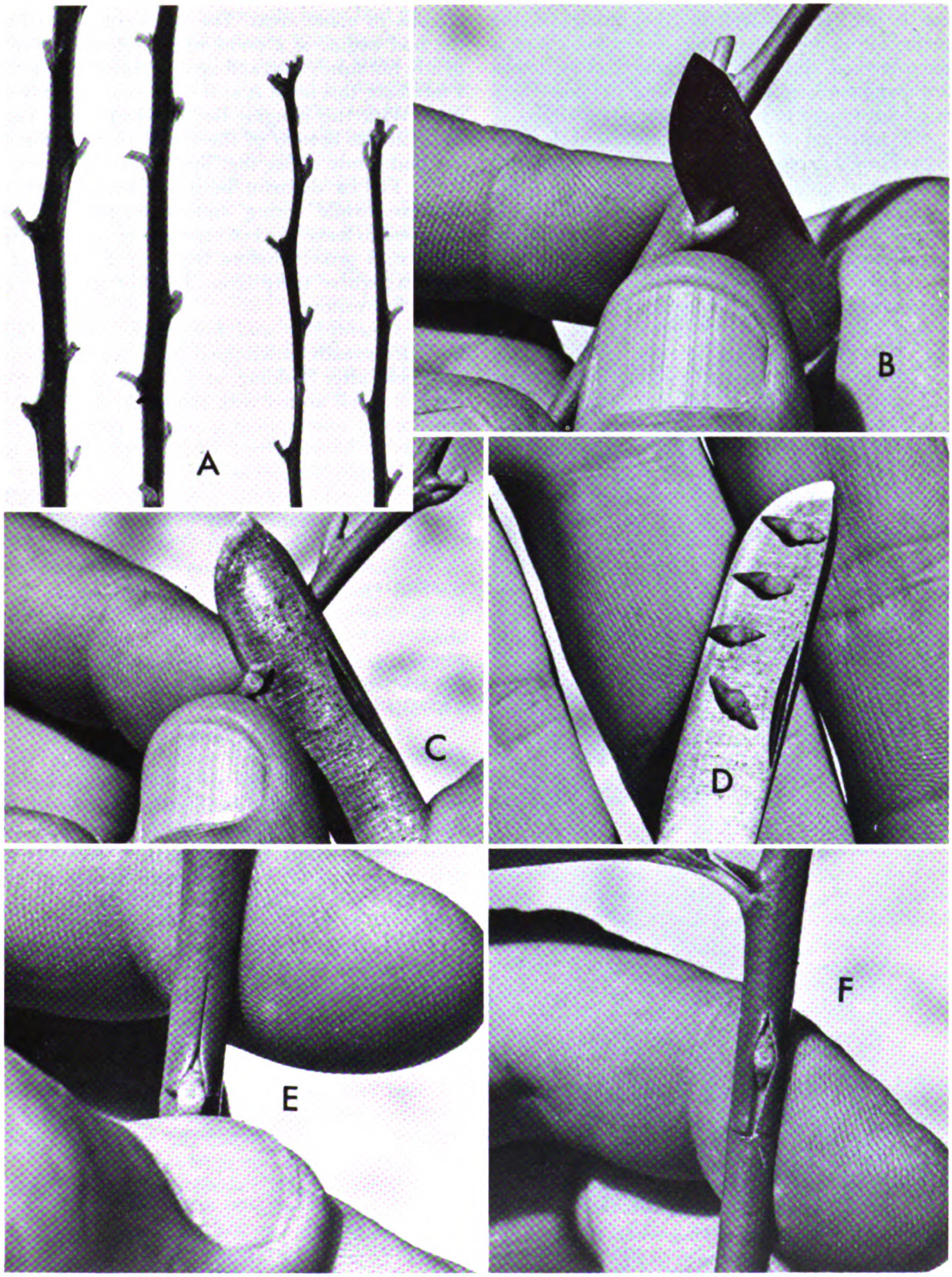

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sap is not running well in (the) stock." In the major citrus areas, however, the wood sliver is not removed and high percentages of bud take are commonplace. In the authors' opinion, there is no advantage in removing the wood sliver.

Insertion of the bud, regardless of method, is performed carefully. All cut surfaces of the bud shield must contact the exposed surfaces of the stock. Ragged cuts increase the possibility of exposure to the air, drying out, and failure of the bud to unite properly with the stock.

For uniformity and ease of handling, most nurserymen bud all the trees at the same height and position in the row. In windy areas, buds placed on the windward side of the seedling make it easier to tie the budshoots as they grow. There is no evidence that the position of the bud in relation to the sun has any effect on bud growth.

As soon as the buds are inserted into the stock, they are tied or wrapped. Waxed cloth, rubber strips, damp raffia, or plastic tape are all suitable wrapping materials. Plastic tape (polyvinyl chloride or polyethylene) of 4 mil thickness and ½ to ⅝ inches in width has proved successful for wrapping. Its ease of handling, elasticity, and moisture-controlling properties make plastic tape a good wrapping material, and it is used by nurserymen in many areas. The wrap used in tying the bud begins at a point which forces the bud gently but firmly into and against the stock. With T incisions, this point is at the junction of the two cuts. With the hanging-bud method, the wrap starts at the bottom of the shield so as to force the bud firmly under the "lip."

Fig. 1–21. Troyer citrange seedling bent to force the bud. Seedling top is held in bent position by tying it to the seedling trunk below the bud.

Fall or dormant buds are wrapped over the eye, while spring and summer buds are wrapped to leave the eye exposed, since the buds often start growth before the wrap is removed. In areas where there is no dormant season, the eye is left exposed.

Unwrapping and forcing the bud.—Fall buds are usually unwrapped from one month to six weeks after budding, at which time they are normally well united with the stock. In Florida, the time of unwrapping is usually governed by the time of banking for frost protection, which is generally mid-November.

Spring buds unite more rapidly than fall buds and are usually ready to be unwrapped in two to three weeks.

There are two common methods of forcing the bud. One method generally practiced in California, is to lop or bend the seedling 2 or 3 inches above the bud (fig. 1–21). The other, practiced in Florida, is to cut the seedling top off just above the bud. Each method is successful in the area where it is practiced.

In California, fall buds are forced just before growth starts in the spring. In Florida, the time of forcing coincides with the removal of the earth bank. Early forcing stimulates uniform budshoot development. Spring buds are forced as soon as the wraps are removed. If there is a delay in forcing the buds, a larger percentage of "sleeper" buds, or buds which fail to grow, may result.

Lopping, as practiced in California, is accomplished by breaking or partly cutting the seedling stem 2 to 3 inches above the bud, then bending the top so it lies on the ground. This, in effect, is a "nurse" limb which provides a food-manufacturing system for the tree until the bud grows and develops enough leaves to adequately maintain the plant. Generally, a larger caliper (diameter) trunk develops faster when the tops are lopped than when they are completely removed.

In some cases, the seedling top is merely bent and tied down to force growth at the bend. This technique is much slower, and often does not force the bud as well. It has the virtue, however, of better preserving the seedling top, and with

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small seedlings it can promote more bud growth. Small budded-seedling stocks grow weakly if the top is lost. If buds fail to produce a shoot within six weeks after lopping, the bend is broken or the lop shaken to make sure the "nurse" top is not too firmly attached. In some cases, "sleepers" may require forcing by cutting off the top.

Maximum benefit from lopping results when lops are allowed to remain attached throughout the spring and summer. In some cases, where bud shoots grow vigorously to a height of 30 inches or more by midsummer, the final sloping cut directly above the bud may be made at this time. In most instances, however, the stub or lop is left until the following spring, and then the final cut is made. Any cutting on nursery trees in the fall increases the sensitivity of the plant to cold injury.

Occasionally bud growth may be weak. In such cases, it can sometimes be forced by completely removing the lop. The stub, however, is left on until the following spring, since too early removal of the stub may cause the trunk to die below the bud.

Healing and callousing of the final cut may be hastened by covering it with an asphalt pruning compound. Some nurserymen have found that painting the wound with Avenarius Carbolineum eliminates or reduces fungus infection at the cut.

A slightly different technique in forcing buds is described by Nauer and Goodale (1964). Working with ⅝-inch diameter seedlings growing in gallon cans in a greenhouse, they sharply bent the seedling about 2 inches above the bud at the time of budding. The top of the seedling was placed under the can to hold it down. Results were compared with seedlings bent at the time wraps were removed three weeks after budding. Nauer and Goodale found a higher percentage of growing buds and greater average budshoot length on the seedlings bent at budding. Similar trials with seedlings in the field, however, did not show these differences.

Budling care.—To develop straight trunks and prevent possible breaking out at the union, citrus budshoots should be supported. Support is normally provided by driving a stake into the ground about an inch away from the budshoot when it reaches a length of about 6 inches (fig. 1–22). Commonly used are 4-foot lengths of 1- by 1-inch redwood, pine heartwood, or cypress, ⅝- by 1½-inch building lath, or 42-inch lengths of stiff metal rods about $\frac{3}{16}$ inch in diameter. When lath is used, the narrow side should be opposite the shoot. This allows the leaves to give some support to the stem and reduces the number of ties necessary to produce a straight trunk.

Fig. 1–22. Budshoots tied to stiff metal rods with raffia to assure a straight trunk and prevent the possible breaking out at the union. Three ties have been used on these budshoots.

The shoot, as it grows, should be tied to the stake at intervals to insure a straight trunk (fig. 1–23). Strong, vigorously-growing budshoots require less ties than those with weak, interrupted growth. Raffia, soft twine, cloth strips, or paper- or plastic-covered wire are used. The ties are made tight enough to give adequate support to the budling and prevent wind whipping, yet loose enough to prevent compression or injury to the bark. When the trees are tied, or more often if necessary, all suckers or sprouts on the main trunk and any originating on the stock are rubbed off before they get large enough to require cutting.

Nursery trees are produced in two main forms (fig. 1–24). One is the "headed" tree in which lateral branches are induced and trained in the nursery. The other is a "whip" or "cane" tree

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Fig. 1–23. Budshoots tied to 1 by 1 inch redwood stakes with raffia to assure a straight trunk and prevent the possible breaking off at the union. Five ties have been used on these budshoots.

in which no lateral branches are formed in the nursery. In California, most growers prefer the "whip" or "cane," but in Florida the "headed" tree is most popular. A preference for the "whip" primarily results from ease of handling and storage, especially when dipping or fumigation for pest control is required. The authors have observed both "whip" and "headed" trees planted side by side, and there were no differences in growth and production. The "whips" naturally develop a satisfactory framework of lateral branches in the field after transplanting.

In producing a "whip" tree, the budshoot is encouraged to grow straight up the stake as high as possible in one season. At digging time, the top of the tree is cut off at a height of 28 to 30 inches. This serves to balance the top and root when the trees are dug. Less suckering and a larger caliper tree results from this method.

The "headed" tree is formed by allowing the budshoot to grow as a single stem one to two feet above the stake. It is then cut back to 28 or 30 inches and three to five well-placed lateral shoots, emerging from the top 4 to 6 inches of the stem, are allowed to develop on the trunk. All other lateral shoots are removed. In Florida, a lower "headed" tree is customary, so the budshoot is normally cut to an 18- to 20-inch height.

Other than staking and training, the cultural practices carried out for the budlings are similar to those described in growing the seedling to budding size. It is desirable that the budling grow rapidly and as continuously as possible. Ample water and fertilizer are required, although in areas of cold winters care must be used to withhold fertilizer applications in time for the budling growth to slow down and harden by winter. The last fertilizer application is made in late summer.

Digging the budling.—Budlings are dug from the nursery row for transplanting to the orchard when they have attained the desired size and during periods of the year climatically suitable for transplanting. Depending on growth rate, this will normally be from one to two years after spring budding or the emergence of fall buds forced in the spring. In areas free from frost, the budlings may be dug and transplanted when they reach the desired size regardless of time of year. Where frosts occur, however, digging and transplanting are started in the spring after the danger of frost is past, and continue until excessive summer heat prevails. Trees should not be dug during dry, windy weather.

The time of cutting back and digging the budling in relation to growth cycle is important. Rohrbaugh (1957) found that nursery trees cut back and dug just prior to a new cycle of growth responded best after transplanting to the orchard. Budlings cut and dug during or immediately after a growth cycle resulted in weak growth. He explained this difference of growth response in the transplanted tree as caused by a maximum storage of carbohydrates in the roots and trunk in the first instance and a depletion of carbohydrate reserves in the second.

Two general methods are used in the digging and transplanting of citrus nursery trees. In the more arid zones, such as California and Arizona, trees are balled, that is, they are dug with a ball of soil adhering to and surrounding the roots. The predominant method in the more humid regions, on the other hand, is to dig and transplant the tree bare root so that no soil adheres to the root system.

Of primary importance is the necessity of preventing the root system from drying out between digging and planting. The balling method

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used in the more arid regions minimizes the chance of roots drying out. Even in humid areas, however, where bare-rooting is practiced routinely, root damage may occur unless stringent precautions are taken to prevent drying.

Trees to be balled are usually trimmed a week or two before digging. This trimming consists of cutting back the top of "whip" trees or cutting back the laterals to a 6- to 8-inch length on "headed" trees. If large cuts are made, the wounds are painted with asphalt emulsion or Avenarius Carbolineum to promote healing.

The shape and size of the ball is largely determined by the tree's root distribution. Larger trees normally require larger earth balls. Enough roots are retained within the ball to insure safe transplanting. Normally, a ball 7 to 8 inches in diameter and 16 to 18 inches in length is sufficient.

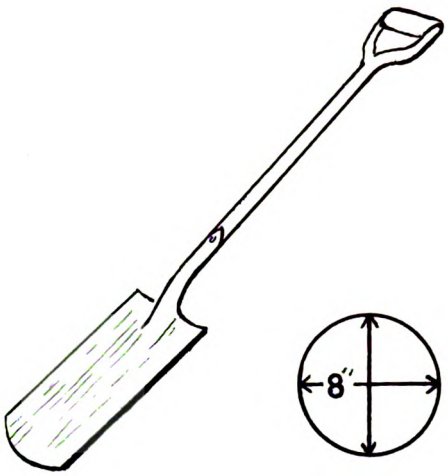

Fig. 1–25. Balling spade 16 inches long. Circle shows diameter of ball.

Fig. 1–24. Balled nursery trees ready for planting. Left, whip tree; right, headed tree.

While an even larger ball would insure a greater number of roots, the size is limited because of weight and handling problems.

In digging balled trees by hand, a long, narrow, straight-bladed spade is used (fig. 1–25). The spade is thrust straight down or slightly inclined toward the tap root about 3 to 4 inches from the trunk on all four sides. This cuts all lateral roots and forms the ball. After the last thrust, the spade is left in the ground and the soil dug away from the back to leave a hole for lifting the ball. The spade is again thrust down on the opposite side of the ball, and the tap root is severed with a shovel (fig. 1–26, *A*). The balling spade is then used as a lever to lift the ball out and onto a piece of burlap for wrapping (fig. 1–26, *B*).

To tie the wrap, the spade is removed from under the ball and the burlap folded tightly over to completely cover the ball (fig. 1–26, *C*). The loose portion of the wrap is gathered round the trunk of the tree and tied in place with twine as close to the soil surface as possible. Two or three evenly-spaced half hitches of twine placed around the ball, drawn up the opposite side, and securely tied completes the wrapping operation (fig. 1–26 *D*).

Trees balled in this manner (fig. 1–27) retain the ball of soil securely around the roots. Such balled trees are handled with care. Rough handling may cause the soil in the ball to shift, thereby severing small, essential feeder roots.

In recent years, several California nurserymen have used balling machines instead of hand balling (figs. 1–28 and 1–29). Essentially the pro-

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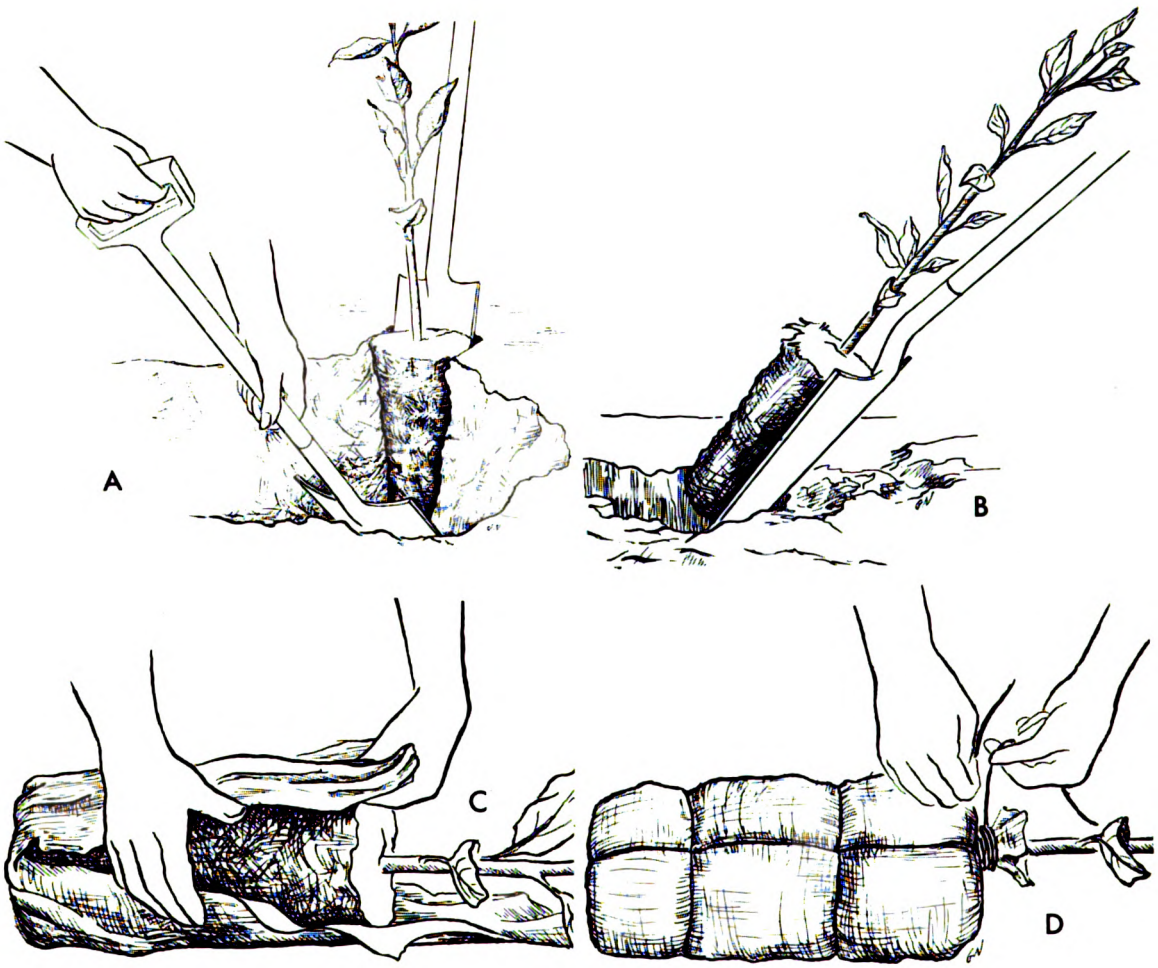

Fig. 1–26 (above). The steps used in balling: *A*, tap root being cut with ball in original position; *B*, lifting ball out of hole on balling spade; *C*, wrapping ball with burlap; *D*, finished ball tied with twine.

Fig. 1–27 (right). The final tie on a well-wrapped balled tree. (Photo courtesy of Sunkist Growers.)

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Fig. 1-28 (left). Balling machine. Tree is dug by forcing a metal cylinder into the soil around the tree thus forming the ball. Cylinder and tree are lifted, the cylinder opened, and the tree with ball of soil slipped into a burlap tube and tied. (Photo courtesy of John Anderson.)

Fig. 1-29 (right). Tree and ball of soil being lifted from nursery row by mechanical-balling machine. (Photo courtesy John Anderson.)

cess and results are the same. The balling machine, however, materially reduces manual labor requirements and has been used where skilled tree ballers were unavailable.

Nursery trees dug and planted by the bare-root method are also cut back and trimmed to a framework or whip, whichever is desired. Generally, all remaining foliage is removed. In areas where sunburn or desiccation may occur, the trunk is whitewashed. In coastal areas, when the humidity is high and the weather cool, bare-rooted trees may be successfully planted with some of the leaves remaining.

To dig the trees, the lateral roots are cut off in a circle around the tree large enough to allow an adequate number of roots to remain connected to the tree. The tree is then lifted with the help of a spade, removed, and immediately covered to prevent the roots from drying out. Materials such as damp sawdust and peat moss covering the roots help prevent moisture loss.

Bare-root trees are normally planted as soon as possible after digging. If they must be held, the trees are kept in a cool, shady place with the roots well protected in damp material.

Balled trees may be held for a day or two in the open if temperatures are moderate and the soil in the balls does not dry out. For storage of a week or two, they are placed under shade and sprinkled whenever necessary to forestall drying out (fig. 1–30).

In some cases, it is necessary to hold dug nursery trees for several weeks or months. When such situations occur, the trees can be successfully held by transplanting them into large, 5-gallon containers. Care must be taken however, not to

Fig. 1–30. Balled trees stored under shade of Saran cloth. A crushed rock base provides drainage under the balled trees.

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hold them in containers until they become rootbound, since this impairs normal root development when they are set out in the orchard. Rootbound trees may never grow to satisfactory orchard size.

Container-Grown Citrus[2]

In recent years, there has been an increasing interest among nurserymen in container-grown citrus budlings in contrast to standard field-grown trees. The method has been employed in growing small lots of trees for research purposes, but has not been generally used for large-scale commercial propagation.

Advantages of such a system include: (1) greater control over infection or contamination by fungus disease and nematodes; (2) the ability to force growth more rapidly by use of "manufactured" soil mixes; (3) greater fertility and environmental control; and (4) an undisturbed root system when the tree is planted in the orchard.

Disadvantages of container-grown budlings include: (1) the production of a smaller tree for orchard planting, which requires staking and more care the first year; (2) the necessity of repotting to larger containers if the tree is to be held over, and (3) the necessity of polyethylene and saran-covered structures for environmental control in some areas.

Whether or not container-grown trees are advantageous depends to a large extent upon the availability of suitable nursery sites and soil, the size of tree required, the preference of the buyer, and the requirement for nursery sanitation. Container-grown citrus has been found advantageous in areas of southern Florida, for example, where suitable nursery soils for field production of trees are difficult to find. It is also used to advantage where freedom from disease and nematodes is required.

Seedlings are grown in plastic-enclosed houses with raised seedbeds or enclosed boxes in a sterilized soil mix (fig. 1–31). A mix found to be satisfactory is a modified U. C.-type soil mix (Matkin and Chandler, 1957) of one-third peat, one-third sand, and one-third wood shavings. This mixture results in good fibrous root development and can be shaken loose on transplanting.

The seedlings are transplanted to containers of a size which will permit root expansion with a minimum of crowding. These may be 1-gallon to 4-gallon cans, depending upon the length of time the tree is to remain in the container (fig. 1–32). Richards, Moore, and Warneke (1967)

[2] The authors are indebted to Paul W. Moore, Superintendent of Agricultural Operations, University of California Citrus Research Center, for much of the information presented concerning container-grown citrus.

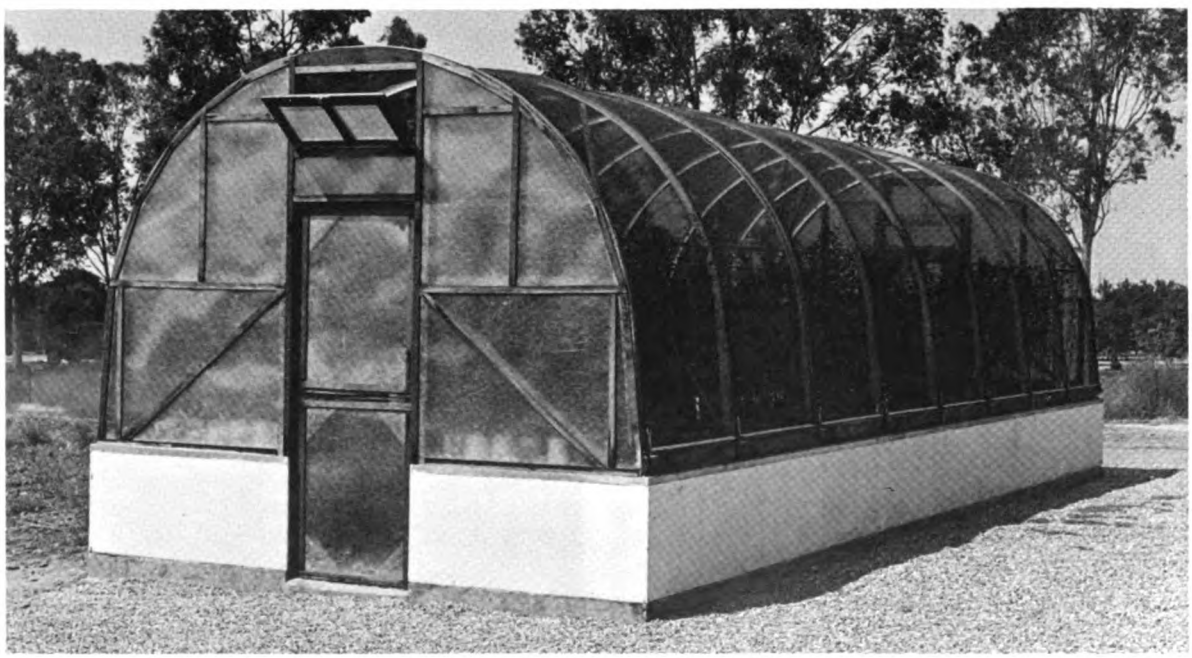

Fig. 1–31. Plastic-enclosed house suitable for growing seedlings.

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found no disadvantage to 0.8-gallon containers if the trees were moved to the field as soon as they reached suitable size for orchard planting. In their trial, this was thirteen months from the time the seedlings were planted. While 1-gallon containers have produced satisfactory trees, it is the authors' opinion that larger containers would be preferable for commercial propagation. They would be less likely to cause root crowding if trees had to be held in the containers for a longer period of time. Trees could be transplanted to a larger container if necessary, but this would involve additional time and labor.

The soil for the container should be one that retains moisture but is relatively porous so excess water may drain away. Again, various mixes may be utilized to create a desirable soil.

When the seedling is established and has attained suitable size, it is budded. Some nurserymen use a veneer bud in preference to the conventional shield bud. Seedlings of smaller diameter may be budded by this method. The microbudding technique described by Wishart (1961) also can be employed with smaller seedlings.

After the bud is united, it has been found advantageous to stub, rather than lop, the seedling to force the bud. The remaining tops, when seedlings are lopped, interfere with the necessary follow-up care in the closer confines of the containers. The normal practices of staking, tying, and suckering are followed.

To assure rapid growth in areas where cool or cold weather may inhibit continuous growth, plastic or saran-covered structures are used to provide protection (fig. 1–33). Temperatures for optimum growth are easily maintained, and trees large enough for orchard planting have been grown from seed in fourteen months under such forced conditions.

THE PROCESS OF UNION IN CITRUS BUDDING

Information regarding the process of union in citrus budding is meager despite the fact that budding techniques are highly developed. The only detailed reports are those of Mendel (1936, 1937), in Israel, who made anatomical studies of the union of Shamouti orange buds on rootstocks of Palestine sweet lime and sour orange.

In his studies, Mendel used fall budding following the inverted-T technique and buds without a wood sliver. In several important citrus-growing areas of the world, buds with a wood sliver have been used successfully for many years. It appears probable that the processes of union using buds with wood would be very similar, if not the same, as those found by Mendel. The same should hold true for other methods of citrus budding and grafting described in this chapter.

Mendel's findings, greatly condensed, are presented below.

Fig. 1–32. Troyer citrange seedlings growing in two-gallon containers.

Fig. 1–33. Saran-covered growing house for container-grown budlings.

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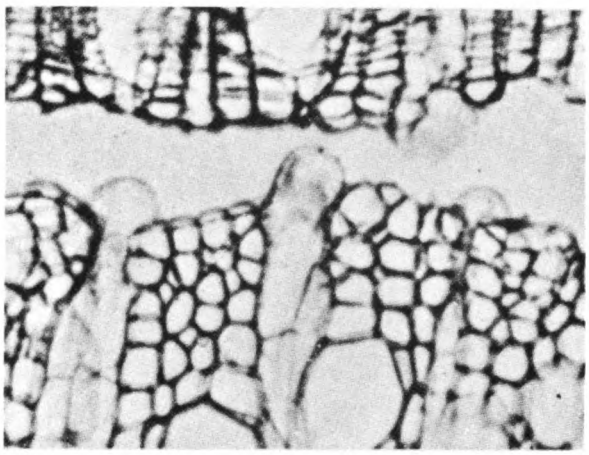

Fig. 1–34. Cross-section through a bud union of Shamouti orange (*above*) on sour orange stock (*below*), 24 hours after budding. Note the newly formed cells at the ends of the medullary rays. These cells are pushing out into the space between the bud and the stock, and are most clearly visible on the stock. X about 330. (After Mendel.)

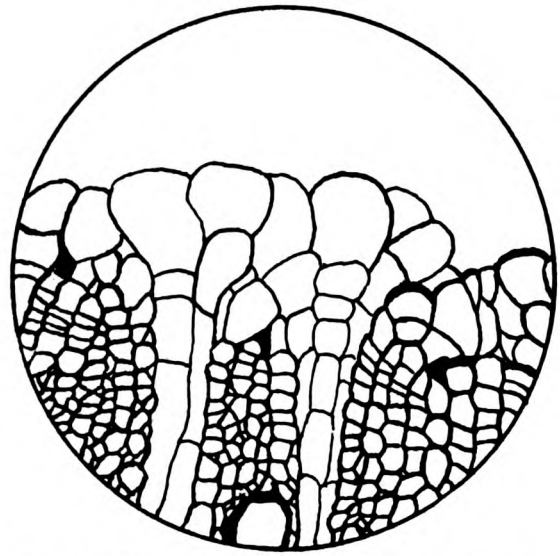

Fig. 1–35. Cross-section through the callus on a sweet lime stock three days after budding. Note the wedge-shaped broadening of the medullary rays, much extended over the development shown in figure 1–34. (After Mendel.)

Callus Formation

Mendel observed that the first stage of healing was the closing of the wound by callus formed by cell division at the surface of tissues adjacent to the wound. The exact time of the first cell divisions varied depending on the degree of tree activity and especially on temperature. In 1930, new cells were found after 24 hours, and in 1932 only after 42 hours. Callus formation occurred first at the injured ends of the medullary rays on the surface of the wood and bark (figs. 1–34 and 1–35) and later from the cells of the wood parenchyma and secondary bark.

Callus formation was found to be most active on the exposed part of the rootstock, less on the raised bark flaps of the T-cut, and least on the bud shield. Mendel noted three cavities created in the wound area: two lateral cavities formed by the raised bark flaps, and a central cavity beneath the shield. Callus filled the cavities under the raised flaps after about 20 days, but took from 25 to 40 days to completely fill the cavity under the shield.

The meeting callus masses occurred first as callus bridges approximately 5 days after budding (fig. 1–36). These provided the first connection between stock and bud. As the callus grew, it produced one gapless tissue in which no cell fusion was observed. Mendel found the only evidence of the junction of united callus masses to be a thin brown layer or "insulating layer." He

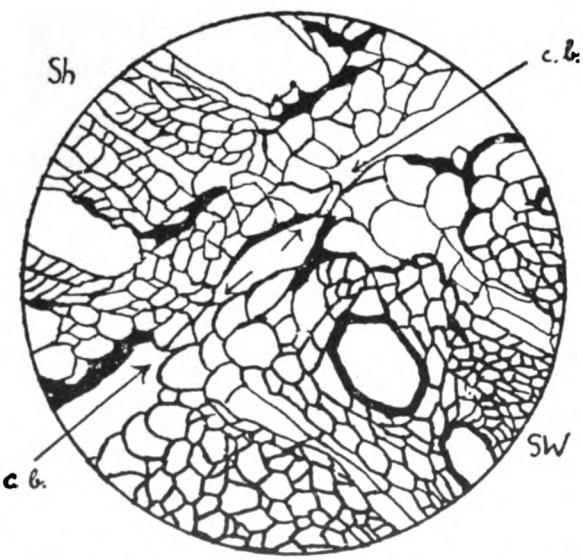

Fig. 1–36. Cross-section of bud union of Shamouti orange on sweet lime five days after budding, showing the formation of callus bridges leading from the wood to the raised flaps. *Sh*, Shamouti; *SW*, sweet lime; *c.b.*, callus bridges. (After Mendel.)

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concluded that this layer was not a primary wound reaction in citrus, as had been described in other plants, but rather a secondary phenomenon resulting from the pressure of uniting callus masses.

Tissue Differentiation in the Callus

The differentiation of callus cells under the bark flaps, Mendel observed, began 10 days after budding as a thickening of the original thin-walled isodiametric cell walls. After 15 days, a number of the callus cells had transformed into tracheids and strands of tracheids, forming rudimentary vascular bundles. Under the shield, tracheid development was not observed until after 20 days.

Cambium Regeneration

The formation of a common cambium ring for rootstock and scion, according to Mendel, was either a process of regeneration of injured or torn cambium underneath the flaps and shield, or one of differentiation where cambium layers connect in the callus. He observed that the cambium was always regenerated in the outer region of the callus—underneath the secondary bark of the rootstock or shield. The union of the cambia of the shield and flaps was, Mendel observed, formed in the callus. A layer of meristematic cells, which became the conducting cambium in the callus, advanced gradually toward the shield and united with the cambium or newly formed meristematic cells laid down in the callus of the shield.

He determined that the formation of the connecting cambium was completed after about 25 days. At this time the process of union was considered complete. In spring budding, the time for the development of the different tissues was less than in fall budding.

Connection of Vessels

A supply of water for the inserted bud is of primary importance after budding. This was provided in a primitive way, according to Mendel, by the first callus bridges 5 days after budding. Later, the differentiation of the tracheid strands in the callus assured a more adequate supply but still not sufficient for the sprouting of the bud. The complete connection of the bud with the wood of the rootstock was completed, therefore, with the establishment of vessels originating in the cambium formed by the callus beneath the shield.

The processes of union, Mendel concluded, is not made up of distinct stages, but represents one continuous process.

OWN-ROOTED CITRUS

When a plant is propagated by means of cuttings, marcotts, or layers, it is said to be "own-rooted." Unless a mutant is involved—a possibility but not a probability—such a plant is genetically identical to the parent.

Own-rooted propagation is used successfully in all citrus areas: for example, marcotts in tropical and subtropical Asiatic regions; cuttings for the propagation of the citron in the Mediterranean area; and cuttings and twig-grafted cuttings for the propagation of dwarf and ornamental citrus in the United States.

One of the principal advantages of propagation by own-rooting is that it is generally more rapid than the standard budded-seedling method. Marcotted Persian limes in southern Florida attain orchard planting size eight months after rooting is initiated. This contrasts with the two to three years required for budded seedlings. Cuttings provide a rapid means of obtaining rootstock material of selections in short seed supply, of varieties having low seed viability, or of varieties producing a low percentage of nucellar seedlings.

The most obvious disadvantage of the own-rooted method is that it eliminates, with the exception of twig-grafted cuttings, the use of a rootstock of a species or variety different from the scion. In standard propagation the rootstock in a budded tree is chosen for its tolerance to soil-borne fungi, better adaption to certain soils, greater frost tolerance imparted to the scion, and its effect on fruit quality and scion vigor. Trees grown as cuttings, marcotts, and layers do not have these advantages. Also, large numbers of trees are more difficult to propagate by own-rooted methods, since they not only require greater amounts of vegetative material but, in the case of cuttings, more elaborate and costly equipment.

In orchard experiments comparing budded trees and cuttings, Halma (1947) found that Eureka lemons on their own roots proved to be less vigorous, less hardy, and less productive than progenies of the same parents budded on grapefruit and sweet orange rootstocks. While the reasons for the inferiority of the lemon cuttings were not clear, Halma assumed it was the result of inherent weaknesses of the lemon which were partly over-

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come by budding on a rootstock of a different species. He discounted the lack of a taproot as the cause, since budded trees, removed after five years in the orchard, had not maintained a taproot.

In similar experiments using Valencia oranges, Halma (unpublished data) found that over an 18-year period the yield and performance of the cuttings was not significantly different from that of budded seedlings. From the disease standpoint, it is interesting to note that in several orchard tests, Valencia orange cuttings were not affected by foot rot (*Phytophthora citrophthora*). In the same locations, however, severe losses from foot rot were encountered with navel orange cuttings (Halma and Opitz, 1952), while navel oranges budded on sweet orange root were not affected.

Fig. 1–37. A four-leaf Atwood navel orange cutting showing root development after three months in the propagating frame (see fig. 1–38).

The authors conclude, therefore, that of the three varieties tested, Eureka lemon, Valencia orange, and navel orange, the Valencia orange would be the one for which propagation by cuttings might be most feasible.

For commercial propagation of large numbers of trees, the budded seedling method is usually the most desirable and practical. For special situations and experimental work, however, own-rooted methods give rapid and satisfactory results.

Cuttings

Many citrus species and related genera may be propagated as cuttings, although some root much more readily than others. Lemons, limes, and citron root most readily. Mandarins are the slowest and most difficult to root. Sweet orange, sour orange, grapefruit, trifoliate orange, and citranges are intermediate in their ease of rooting.

Recent investigations and experience confirm the basic methods described by Halma (1931). Some modifications in rooting medium and humidifying systems have been adopted as they became available.

Cuttings are made from recently matured terminal growth consisting of a single flush taken from healthy, vigorous trees. Tree vigor and health is especially important with the intermediate or hard-to-root species. Cuttings taken from young clones of any species root more readily than those taken from old clones. Ford (1957), working with leaf bud cuttings (see below, p. 35), found that the physiological age rather than the chronological age of cutting material was important. He compared leaf bud cuttings from root sprouts with those from recent growth in the tops of fifteen-year-old sweet orange and sour orange seedling trees. The percentage of rooting after thirty-five days was approximately three times as great for cuttings from root sprouts as for those from recent top growth. This would indicate that juvenility, as expressed in the root shoots, and ease of rooting are closely associated.

Root development from very young seedlings is almost as taprooted as that in seedlings, while roots from old clones tend to be more lateral.

The largest amount of desirable wood for cuttings is normally found in early summer to midsummer following maturation of the spring growth flush. In areas where several growth flushes occur during the year, however, satisfac-

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tory cuttings may be obtained at most any season. Some propagators prefer winter cuttings taken from the north side of the tree. These root well if the trees have been maintained in good condition throughout the fall and winter. Frost-weakened trees and those suffering from nutritional deficiencies, insect damage, or disease are poor sources for cutting material. Shoots from trees recently sprayed with oil for pest control do not furnish satisfactory cuttings, since leaf drop usually occurs when the cuttings are placed in the propagating frames, and defoliated cuttings do not root satisfactorily.

Length of the cuttings ranges from 3 to 6 inches. The basal two or three leaves are removed to permit the cutting to be placed in the rooting medium. Three to six terminal leaves are left on the cutting (fig. 1–37). It is important to keep cuttings moist after removal from the tree and during all subsequent handling.

More roots and a better root distribution result from a basal cut squarely across the end of the cutting. A slanting cut tends to produce fewer roots. Notches or grooves at the cut ends, while increasing the number of roots, do not increase the total volume of roots. In relation to buds on the stem, the position of the basal cut is of no consequence.

The formation of roots on cuttings of some kinds of citrus is improved by treatment with root-inducing hormones. The effect of hormones, however, is not uniform with all citrus. Cooper and Knowlton (1940) immersed the basal end of cuttings in a 0.02 per cent aqueous solution of indoleacetic acid for 24 hours. They found a definite increase in the percentage of cuttings striking roots and in the number of roots per cutting on Villafranca lemon, rough lemon, Morton citrange, Conner grapefruit, Marsh grapefruit, sour orange, Homosassa sweet orange, Bergamot orange, Suen Kat mandarin, and Cleopatra mandarin. Woglum lime, Rangpur lime, and Hong Kong kumquat showed only an increase in the number of roots per cutting. In a parallel test, all of these citrus cuttings were also treated by dipping the moistened basal ends into a dust mixture consisting of 1 mg of napthaleneacetic acid per gram of talc. This treatment, however, showed no increase in root formation over the controls, except in the case of the lime and lemon.

Other workers have had similar results. Biale and Halma (1938) using 3-indoleacetic acid in varying concentrations, found that grapefruit and Valencia orange showed a marked increase in percentage of rooted plants over controls, but that lemon and citron rooted just as well without treatment. The number of roots, however, was considerably greater on the treated cuttings.

Erickson and Bitters (1953) studied the response of cuttings from plants representing six genera of Rutaceae to four plant-growth regulators at two concentrations. The treatments included 0.2 and 0.4 per cent of α-napthaleneacetic acid (NAA), 0.2 and 0.4 per cent of indolebutyric acid (IBA), 0.05 and 0.1 per cent of 2,4-dichlorophenoxyacetic acid (2,4-D), 0.05 and 0.1 per cent of 2,4,5-trichlorophenoxyacetic acid (2,4,5-T), and the control. Each material was incorporated with talc and applied as a dust to the moistened basal end of a 2- to 3-inch cutting containing one or more leaves. No significant improvement of rooting was observed on cuttings of *Atalantia citroides* Pierre ex Guill. with any of the growth regulators, although numerical improvement was shown with 0.2 per cent of IBA. Cuttings of *Clausena lansium* (Lour.) Skeels showed significant rooting improvement with 0.05 per cent of 2,4,5-T. *Microcitrus* cuttings responded significantly to 0.4 per cent of NAA. Cuttings of *Murraya paniculata* (L.) Jack responded significantly in per cent rooting to 2,4-D and in root length to 0.05 per cent of 2,4,5-T. Cuttings of *Severinia buxifolia* (Poir.) Tenore showed no significant response other than an apparent toxicity to 2,4,5-T at the concentrations used. *Citrus limon* (L.) Burm. f. (Eureka lemon) rooted well without treatment, but cuttings showed more rapid rooting and greater root growth with NAA and IBA. Treatments with 2,4-D and 2,4,5-T were slightly toxic to this species.

In commercial practice, California nurserymen who propagate by cuttings have found that most varieties respond to a treatment of indolebutyric acid (IBA) in talc at a concentration of 3,000 to 8,000 parts per million. A bead of free moisture at the base of the cutting prevents the powder from adhering; hence, the cuttings are dipped damp, not wet, into the powder and placed at once into the rooting medium. Kinds of citrus more difficult to root, such as the satsuma mandarin, benefit from quick dip into IBA at a strength of 10,000 parts per million. This solution is made by dissolving 20 mg of IBA crystals in 1 cc of alcohol and adding an equal volume of water. The base of the cutting is dipped ¼ inch into the solution for one or two seconds and then placed in the rooting medium.

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Fig. 1–38. A simple closed propagation frame for the propagation of cuttings. Note thermostat at inside lower right corner of frame which regulates soil temperature through a soil-heating cable.

Cuttings strike roots in any structure that maintains high humidity and provides good light intensity. Two general types of rooting structures are used. One, the closed propagation bed or frame, has been used successfully for commercial propagation of Troyer citrange cuttings (Opitz, 1951). This type of structure is easily installed, but requires frequent attention to humidity, light, and temperature (see fig. 1–38).

The other type utilizes the mist system for maintenance of high humidity. Here, the propagating beds are on benches within a structure designed to provide sufficient light, but at the same time prevent desiccation from drying winds. Mist systems utilize periodic fogging controlled either manually or automatically. Citrus cuttings under mist tend to leach badly if they are slow to root or if they are left in the rooting medium too long. Nutrient spraying and lengthening the intervals between mistings as soon as roots form reduces nutritional losses.

Most investigators have found that the minimum temperature for rooting is 75° F, and the optimum for most varieties appears to be between 80° and 90° F (Halma, 1931; Ford, 1957; Ryan, Frolich and Kinsella, 1958). Bottom heat to maintain soil temperatures of from 80° to 90° F is usually required during all but the warmest seasons. Too high an air temperature (above 95° to 100° F), particularly if accompanied by lowered humidity, causes the leaves to wilt or burn to the detriment of successful rooting. In closed frames, temperature may be controlled by adding or removing shade and by increasing or decreasing the frequency of sprinkling.

Rooting media may be any of several well-aerated materials. Builders' sand, equal mixtures of sand and peat, vermiculite, and perlite have all been used successfully. For convenience of handling, the rooting medium generally is placed in flats. The cuttings are set about 1½ inches deep and spaced far enough apart so that at least a portion of every leaf is exposed to light.

After development of 4 to 8 inches of total root growth per cutting, the cuttings are hardened off by gradually reducing the humidity in the frames. If the mist system is used, the "on" period is shortened until the cuttings no longer require moisture on the leaves to prevent wilting. As soon as the cuttings are ready, they are transplanted to containers or to the nursery row. Lemon cuttings normally produce enough roots to permit removal from the propagating frame in four to six weeks. Oranges may be removed in six to eight

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weeks and mandarins in four months or more. Some variation must be expected depending upon temperatures and humidity during propagation and the original condition of the cutting material.

In hot or dry weather, cuttings lined out in nursery rows need protection from direct noonday and afternoon sun. This may be provided by a shingle placed on the side of the cutting receiving the afternoon sun to help the plant adjust to its new environment. Cuttings transplanted to containers are placed under lath or partial shade until the roots have established themselves in the container.

Leaf Bud Cuttings

Leaf bud cuttings provide a means for the propagation of larger numbers of citrus plants if the parent material is in limited supply. Basically, the only difference from that of the standard method of producing cuttings is in the number of buds per cutting. Leaf bud cuttings contain only a single bud, while the standard cutting has five to nine buds.

Watkins and Blackmon (1939) described the technique as "the taking of a bud with a single leaf attached, exactly as though it were to be used in shield budding. The comparatively small cutting is inserted in a congenial rooting medium so that the shield of the wood is just covered, allowing the lamina to lie flat or nearly so."

Ford (1957) used leaf bud cuttings to propagate limited rootstock sprout material in Florida. Instead of a shield, however, he cut the stem above and below each bud so that the cutting consisted of the single leaf attached to a piece of stem, 1 to 2 cm long. In a test of several rooting media, types of beds, and misting methods, he concluded that for large-scale propagation the most economical and satisfactory method was to use ground beds with a translucent cover, a mixture of German peat and perlite as the rooting medium, and constant or intermittent mist during daylight only. Bottom heat set at a minimum of 90° F was found to increase the rooting percentage.

Twig Grafting

Twig grafting, described by Halma (1931), is a modification of propagation by cuttings. In this method, two leafy twigs are grafted together by means of a whipgraft and the lower one is rooted. This produces a plant with the desired rootstock-scion combination. Three cuttings grafted together create a plant with rootstock, scion, and interstem, each of a different species, if desired.

The same type of vegetative material used in propagation by cuttings is employed. Care is taken, however, to select material that will be of equal diameter at the point at which the graft is made. At least three leaves are left on the top or scion piece, at least one leaf on the lower or stock piece, and one leaf on the interstem, if it is used. A sloping cut ½ to ¾ inches long at approximately a 15-degree angle is made at the upper end of the rootstock piece and at the base of the scion piece. The two cut surfaces are brought together so that they cover each other and are wrapped with several turns of raffia or rubber strip (fig. 1–39). Some experience is necessary to judge the tension of the wrap. If too loose, the pieces spread apart or shift; if too tight, the bark will be damaged. Cut surface edges are not sealed, since the high humidity provided for rooting protect them from drying. Immediately after wrapping, the grafted cuttings are placed in the rooting medium in the same manner as described for cuttings.

Fig. 1–39. Twig-grafting lemon on trifoliate orange; Left, cuts at top of rootstock and base of scion; Center, rootstock and scion tied with rubber strip; Right, the same combination after two months in propagating frame.

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Graft unions heal in three or four weeks, at which time the wrap is loosened or removed. The time required for the basal piece to root depends upon the kind of citrus used. Ryan, Frolich, and Kinsella (1958), working with easy-to-root material (rough lemon and sweet orange) and difficult-to-root material (sour orange and kumquat), found that the presence of a grafted piece on the cutting had no effect on the ease of rooting.

Growers of ornamental and dwarf citrus utilize twig grafting as a rapid and successful method of producing trees (Dillon, Real, and Dillon, 1962). In experimental work, this method offers a means for the vegetative reproduction of specific clonal combinations.

Layering

Propagation of citrus by layering is not common, although in some areas of the world trees are propagated by this method. For many years, layering was the principal method of propagating citrus in South Africa, and trees started as layers a hundred years ago are still producing. In subtropical Asian regions, a type of layering known as marcotting has been used with success. For large numbers of trees, however, layering is an inefficient method of propagation. Thus, in some areas where it was once used extensively, layering has given way to propagation by budded seedlings.

In propagation by layering, a branch or limb is caused to root while still attached to the parent tree. After sufficient roots form, the rooted portion is severed from the parent and planted as an individual.

Fig. 1–40. Propagation by layering. Branch bent down with cut tip of end buried in soil.

Layering is usually done in the spring by selecting a basal limb of sufficient length and bending it until it touches the soil. The *lower* side is then cut about halfway through so the terminal end can be brought to an upright position. A small hole is dug in moist soil at the point where the bottom of the shoot will be placed. The tip of the branch is bent upward, and the cut portion at the bottom is lowered into the excavation (fig. 1–40). Moist, friable soil is carefully packed around and over the cut end to a depth of 5 or 6 inches. If the limb is under tension from bending, it must be staked down to hold the buried end firmly in place. Should the parent branch be too high or too rigid to bend easily, it may be cut halfway through on the *upper* surface to permit bending it at a sharp angle. It must still remain attached to the parent tree, so that it will receive water and nutrients until it has rooted. The limb buried in this manner is left undisturbed in moist soil until the following spring when it should be well rooted. It is then dug up, cut loose from the parent tree, and planted in the orchard.

It is doubtful, except under special conditions and in areas where little care is required to tend the layers, that this method of propagation will find widespread use.

Ring Method of Layering.—A type of layering known as the ring method has been described by Oppenheim (1932). Hard-to-root species have been successfully rooted by this method, and the root system is said to be better developed than those from cuttings.

To propagate by the ring method, a year-old seedling is cut back in early spring to a height of 6 to 8 inches, forcing several branches to develop along the trunk. When, in about six weeks, the branches on the lower part of the trunk have become rounded and hardened, they are bound with three or four turns of thin copper wire at a point about 2½ inches from the seedling trunk. The wire is secured snugly, but not so tight as to injure the bark. Moist earth is then heaped around the seedling to a height of 4 to 6 inches above the highest ring. Two-thirds of the branches on the seedling may be ringed, leaving the upper branches to provide the normal nutrition to the roots. The mound of soil must be kept moist until the ringed branches are well rooted. When sufficiently rooted, usually in three to four months, the layers are removed from the parent seedling and transferred to containers or the nursery row.

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Marcottage

A type of layering especially adapted for use in humid regions is a system of propagation known as marcottage or air layering. As previously mentioned, it has been generally confined to subtropical and tropical Asia, although in recent years marcottage has been one of the methods used for propagating Persian limes in southern Florida.

In marcotting, a conveniently placed small twig or branch on the parent tree is selected. It is girdled at a point 12 to 18 inches from the end by removing a ½-inch strip of bark or tonguing by an upward cut with a small splinter of wood placed under the tongue to hold it apart. The girdled area is immediately covered above and below with a ball of moist sphagnum moss, coconut fiber, or clay. This rooting medium is then encased with cloth, burlap, aluminum foil, plastic film, or rubber tubing (fig. 1–41). The encased rooting medium forms an elongated ball of 4 or 5 inches in diameter, which may have to be supported by attaching it to larger limbs or to stakes driven into the ground. Should the ball dry out, the marcott will be lost; consequently, it may require frequent wetting.

In southern Florida, marcotts are made in August or September, before the trees enter dormancy. Although successful at other times of the year, marcotts begun in these months will be ready for planting in the orchard at the start of the rainy season in June (Sutton, 1954).

Six to ten weeks are generally required for sufficient roots to form in the moist ball so that the marcotts can be safely removed from the parent tree. It is the usual practice in Florida to place the marcotts in containers for three to four months before planting them in the orchard, thus assuring proper balance of top and roots. It is advisable to prune the top moderately before planting.

Fig. 1–41. Sphagnum moss encased by plastic film to cover girdle on branch and promote rooting of marcott.

REPROPAGATION METHODS

Since propagation connotes multiplication, and since topworking, inarching, and bridge grafting serve to perpetuate the plant by utilizing propagation techniques, the term repropagation describes more accurately these methods of changing or preserving citrus trees.

Topworking

Topworking of established citrus trees is sometimes desirable for a number of reasons. In some cases, it is advantageous to change to a different species or variety when the original selection is nonproductive, of poor quality (Opitz, 1961), or an off-type. In other cases, it is necessary to topwork cold-damaged trees to establish new tops. In still other instances, trees threatened by virus disease may be saved by topworking to a tolerant scion.

Topworked trees usually become productive sooner than nursery trees because of the already well-established root system. Growers often topwork because it is less expensive than removing the old stump and planting a new tree.

In topworking, the tree to be worked must be basically vigorous and free from virus and fungus diseases. Both rootstock and interstock should be compatible with the new top (Platt, 1959). If lemons are to be topworked on sweet orange-sour orange combinations threatened with tristeza, this must be done before the trees are infected with the virus (Batchelor and Bitters, 1953; Schneider and Wallace, 1954; Platt, 1959).

Citrus trees can be topworked either by budding or grafting. Both methods, with variations, are used on all sizes of trees. When bud-

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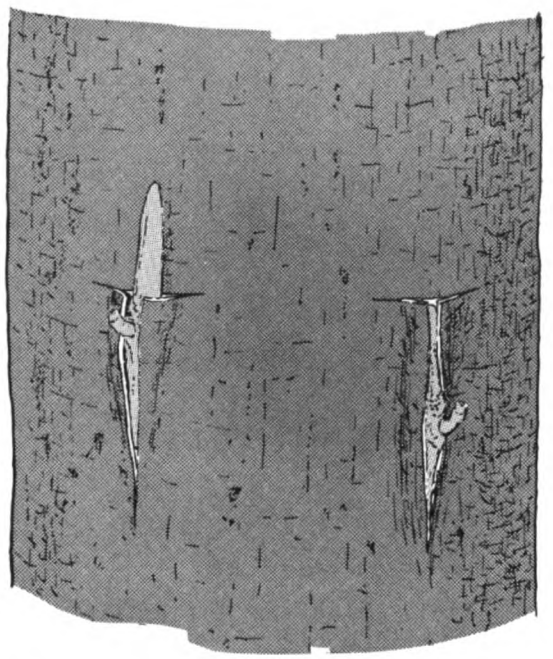

Fig. 1–42. Topworking by budding. Left, bud partially inserted in T cut on branch or trunk. Right, bud inserted and ready for wrapping.

ding, the shield bud is generally used, although in some areas other types are preferred. In western Algeria, for example, the patch bud is widely used (Blondel, 1952). Similarly, in grafting, the bark graft is most commonly employed; however, in some cases, the cleft graft (Camp, 1957) and the side graft (Blondel, 1952) are preferred. The method chosen depends upon tree age, tree condition, and the experience and preference of the propagator.

In most areas, young trees are budded and large, old trees are grafted; however, in Florida, vigorous shoots are forced from old trees and buds are placed in them. The same method is generally employed on old trees in Arizona (Tate, 1954). In central California, budding is preferred for trees of all ages because it is faster, less expensive, and requires a smaller amount of propagative material. In southern California, several blocks of large, old seedling oranges have been successfully topworked by bark grafts (LaRue, 1950; Anonymous, 1951).

Under certain conditions, other methods are sometimes employed. In the tropical climate of the Philippines, for example, Gonzalez and Casal (1950) report that graftinarching gives better results than either bark grafting or shield budding in topworking old pummelo trees. Such methods are not in general use, however.

Topworking by Budding.—In California, the most widely used method of topworking is that of placing a shield-bud directly into the trunk or scaffold limbs of the tree.

Budding may be done either in the fall just prior to tree dormancy or in the spring as soon as the bark slips well. Buds placed in the fall are held dormant by not cutting back or girdling the branches until spring. Spring buds are forced three or four weeks after budding, either by cutting back the branches or girdling by removing a ¼-inch strip of bark completely around the branch, 2 to 3 inches above the bud. Fall buds are forced in early spring in the same manner.

Immediately before inserting the buds, a selection is made of the branches or trunk area that will receive the buds, and small limbs in the budder's way are removed. Branches not in the way or not needed for budding are left untouched to serve as nurse limbs for the tree.

To insert the bud, a T cut is made in the limb or trunk, the bark is lifted, and the bud is slipped snugly against the stock (fig. 1–42). If the bark is too thick to manipulate without cracking, it should be thinned with a knife to about ⅛ inch. The bud is securely tied in with waxed budding-cloth or plastic tape. Budwood selected for topworking is larger in diameter (¼ to ⅜ inch) than budwood used in nursery budding. Also, the shield cut with the bud should be from 1½ to 2 inches long to prevent bark growing over and smothering it.

The number of buds placed per branch or trunk depends somewhat on the size of the tree. Two to three buds are usually placed on stock up to 4 or 5 inches in diameter. These are placed so the growing buds make a strong union and result in a well-formed tree.

After three or four weeks, the wraps are removed and the buds examined to see if they are alive. If callus tissue has overgrown the bud, the excess tissue is carefully cut away to permit the eye to produce shoot growth. If the buds are living and appear to be well callused in, the budded limbs are shortened or girdled as previously described to stimulate bud growth. For fall buds, this is done the following spring.

As the shoots grow, they may be tied to the stumps of the girdled and defoliated branches. In windy areas, additional support and pruning to induce branching may be necessary to prevent the new shoots from breaking out. After the

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shoots have developed a top sufficient to nourish the root system, the branches or trunk are cut off flush with the bud and the surface sealed with a pruning compound. The final cut is made at an angle to promote more rapid and complete healing.

In Florida and Arizona, and to some extent in California, buds are placed in vigorous new shoots arising from heavily cutback trees. Buds placed in new shoots usually "take" easier than buds placed in older wood, but time is lost growing the shoots and more follow-up work is required. Procedures for budding into new shoots are essentially the same as for nursery trees. In hot, arid climates, care must be taken to prevent sunburn when trees are cut back to produce shoot growth. For this protection in the northern hemisphere, some branches are left on the south and west side of the tree, and those on the north and east side are cut back. All exposed areas are whitewashed.

Regardless of method, it is wise to identify the growing bud in some manner that will distinguish it from adventitious buds arising nearby. A spot of paint at the base of the bud prevents its inadvertent removal during the pruning and pinching of adventitious shoots necessary to force the desired bud.

Topworking by Grafting.—The bark graft is most commonly used when large, old trees are topworked by grafting. Scions are set in the main scaffold branches after they have been dehorned or are set directly into the trunk following removal of the top of the tree. When grafting into scaffold limbs, some branches are left as nurse limbs both for shade and to maintain the root system until the new scions develop foliage. Bark grafting is done as early in the spring as the stock bark will slip. This permits the scions to develop maximum growth before cold weather comes.

About a day after removal of the branches preparatory to grafting, the bark tightens. Therefore, if the grafting is not done immediately after cutting, it will be necessary to wait about one month until the bark loosens again, at which time the stump may be recut and grafted. Scionwood selected for the grafts is from firm, current season's growth, ranging from $\frac{3}{16}$ to $\frac{3}{8}$ inches in diameter. Younger wood and wood as old as two or three years is sometimes used, but with less success. LaRue (1953) compared four ages of scionwood used in a topworking trial in California as follows:

Type of Wood	*Successful Grafts (Per Cent)*
Young, angular, green	57
Round, green	43
Green-barked hardwood	72
Grey-barked hardwood	14

Although the exact age of the wood was not noted, it seems likely that the green-barked hardwood describes firm, current season's growth.

The bark graft (fig. 1–43) is made by cutting vertical slits, 2½ to 3½ inches long, through the bark and down to the wood. These are spaced 3 to 5 inches apart around the freshly cut stub. The scions are cut 5 to 6 inches long with four to six buds per scion. If longer than necessary, scions are liable to dry out before healing. A sloping basal cut about 3 inches long is made on one side of the scion. In some cases, a short, sloping cut is also made on the opposite side to facilitate insertion in the vertical slit made on the stock. The bark on one side of the cut in the stock is lifted with the grafting knife. The scion is inserted and pushed down this side of the slit with the long cut surface of the scion facing the wood of the stock. One edge of the scion fits snugly against the unlifted bark on the stump. A little of the cut surface on the face of the scion should be visible above the rim of the stump after the scions are inserted.

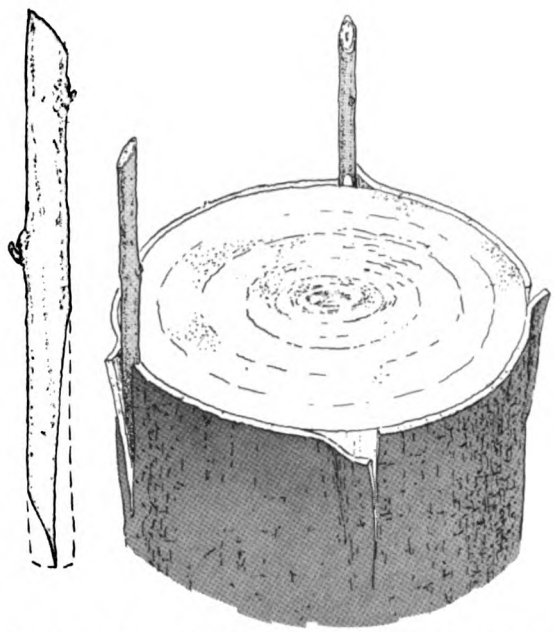

Fig. 1–43. Topworking by bark grafting. Left, scion, showing two basal tapered cuts. Right, stock, showing vertical slits in the bark and two scions inserted and ready to be secured to the stock.

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A slight variation in the method of preparing the scion is described by LaRue (1953). He suggests that one edge of the long, sloping cut be trimmed so that the scion will fit more snugly against the unlifted bark on the stump.

The scions may be nailed in place with thin, flatheaded nails, or several loops of strong cord or friction or vinyl tape may be tied around the stump. On very large stumps, baling wire is sometimes used successfully to bind the scions. Care must be taken to insure a good fit and enough pressure to hold the scions securely at a point where the top edge of the stump and the cut surface of the scion join. Most of the strength of the new union is in this area. After the scions are bound and secure, all cut surfaces are sealed with a grafting compound to prevent drying.

After grafting and sealing, the scions and trunk require protection against sunburn. This may be accomplished by whitewash spray or paint on the sunny side and shading by ventilated paper bags or burlap on light wooden frames erected over the grafts. As the scions start to grow, the paper bags are torn sufficiently to permit the shoots to emerge into the sunlight without hindrance. The grafts are checked frequently to prevent ties from binding and to renew the grafting compound where it is needed.

In moderate climates, a white, water-thinned latex paint applied over the entire stump and scions is often substituted for the paper bag or burlap shade.

In areas of strong wind, 1- by 2-inch boards are nailed to the stump for support, and the shoots are tied loosely to them. Some propagators prevent breakage by cutting or pinching back longer shoots to keep them short and bushy. Excessive pruning of the new shoots delays growth, however, and supports are needed if maximum shoot growth is to be obtained.

All adventitious shoot growth on the stump around the grafts is rubbed off to eliminate rootstock or interstem competition with the new top. As with trees topworked by budding, it is wise to identify the new scion with a spot of bright paint so it may be easily distinguished from buds arising from the stock or interstem. This is especially important where vegetative characteristics of the new scion and stock are similar. Nurse limbs are not cut back or removed until they start to interfere with the growth of the scion. In colder areas, a certain amount of crowding of the new scion foliage with that of the nurse limbs is considered desirable during the first winter for cold protection.

Inarching

Inarching consists of uniting limbs, parts of limbs, or different trees by a process similar to both budding and grafting. Many types of inarching have been practiced, but only the most common will be discussed here.

In commercial practice, inarching is employed when it is desirable to save trees whose

Fig. 1–44. Original Washington navel orange tree in Eliza Tibbets Memorial Park, Riverside, California, ninety-six years after inarching.

Fig. 1–45. Trunk of tree in figure 1–44 forty-seven years after inarching. (Photo by Dr. L. J. Klotz, July, 1944.)

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trunks or root systems have been damaged or girdled by disease, rodents, and mechanical or chemical injury. A notable example of its use in saving a tree from disease, in this case foot rot, is that of the original parent tree of the Washington navel orange at Riverside, California. Today, forty-seven years after inarching, and ninety-six years after propagation, the tree is still alive (figs. 1–44 and 1–45). In such cases, it is necessary that inarching with seedlings compatible with the scion be done as soon as possible following such bark injury. Inarching has also been successfully practiced by growers in Brazil to establish a tristeza-tolerant rootstock on trees of susceptible combinations that were threatened with the disease. Where virus diseases are involved, the species of seedling used as the inarch must be tolerant to the virus diseases which already infect the tree. For example, it would be a waste of time to inarch a citrange or trifoliate orange seedling into a tree infected with the exocortis virus.

To inarch with seedlings, holes are dug as close to the tree trunk as possible and deep enough to accommodate the seedling roots. The seedlings should be ⅜ to ½ inch in diameter and may be balled. If provisions are made to keep the roots moist, seedlings may be bare root. Usually the seedlings are defoliated to reduce moisture loss. Two or more seedlings are generally planted to better insure chances for tree recovery. Valuable, large trees with extensive bark or root injury may utilize six or eight inarches.

The seedling is placed in the prepared hole at the base of the injured trunk as if for planting. The point well above the area of injury where the top of the seedling will be inserted in the bark of the trunk is marked. The seedling stem to be inserted is cut with a long, even slope. A successful propagator (Knowlton, 1959) recommends that this cut be slightly hollowed for a better contact. An inverted-T (⊥) incision is then made on the trunk of the tree, on a ridge rather than in a hollow, and the cut tip of the inarch is pushed upward into the incision, which is wrapped or covered with grafting tape and sealed with asphalt emulsion or grafting wax (fig. 1–46). On larger trees, a thin, flatheaded nail is driven through the seedling into the trunk to secure it firmly. Prior to inserting the inarch, the propagator may drill a small hole in the seedling to admit the nail without splitting the seedling. After the inarch is properly placed, secured, and sealed, the soil is filled in around the seedling roots and thoroughly irrigated.

Inarching succeeds only when the bark slips. Frequently, damage to trees occurs or remains unnoticed until it is too late to inarch. Under such circumstances, the tree to be inarched is identified and preparations must be made for inarching at a favorable time.

Occasionally, sprouts emerging beneath an injury can be used to bridge the damaged area. These are handled in the same manner as seedling inarches except that planting is not required since the sprouts already connect with the root system.

Whether seedlings or sprouts are used, shoots arising from buds on the inarches are allowed to grow until the graft union is well callused. When callusing occurs, these rootstock shoots are removed and all ensuing shoot growth is suppressed.

A modification of inarching, employed in Florida and practiced to some extent in other areas, is that of planting and establishing the seedling to be used as the inarch before the actual graft is made. Under many conditions observed by the authors, however, it is difficult to successfully establish seedlings in the shade of a large tree and additional time and care is required.

Bridge Grafting

Bridge grafting is practiced in cases where the root system of the tree has not been damaged, but where there has been considerable injury to the bark of the trunk. To save the tree or hasten

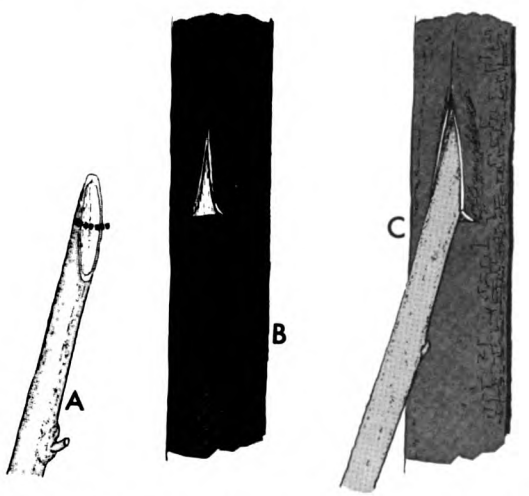

Fig. 1–46. Inarching. *A*, cut end of rootstock seedling showing sloping cut with slight hollow to fit curve of trunk; *B*, inverted-T (⊥) incision in bark of trunk; *C*, inarch inserted and ready to be secured.

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Fig. 1–47. Scion rooting from Lisbon lemon scion severely overgrown on grapefruit rootstock. A soil mix, mounded over wounded areas on the scion and up around the trunk, has been removed for the photograph thus exposing the roots. (Photo by H. Schneider.)

recovery, a number of scions may be inserted to bridge the wound.

Scion wood chosen is similar to that used for bark grafting in topworking citrus trees. Before insertion of the scions, the damaged area is trimmed back to healthy, undamaged tissue. Scions which have been shaped with a long sloping cut at each end are inserted perpendicularly and right side up under the bark at the upper and lower edges of the injury at 2- to 3-inch intervals. The scions are cut long enough to bow slightly outward when in place. The bow allows good contact at each end and permits some flexibility to prevent loosening of the scions by wind.

The scions are nailed after insertion, and all cut surfaces are carefully covered with a grafting compound. Buds on the scions frequently produce shoots which are removed as they appear.

OTHER METHODS OF PROPAGATION AND REPROPAGATION

Several other methods of propagation are used under special circumstances or conditions. These are generally variations or combinations of the methods already described. Some have been found advantageous for experimental work, but have not been tried or proven practical for large-scale commercial practice.

Root Grafting

Root grafting, a method of propagation of the rootstock of mature trees, has been described by Halma (1931) as an adaption of twig-grafting. It consists of grafting a healthy citrus twig, 4 to 6 inches long and with three to four leaves attached, to a root piece of the same length and about ⅜ inch in diameter. The tongue, splice, cleft, or bark graft may be used. The graft is tied with a rubber band or raffia, placed in a propagating bench, and treated like a cutting.

Scion Rooting

Scion rooting provides a means of invigorating or saving a tree by inducing root development from the scion (fig. 1–47). It is used where trees have declined from foot-rot infection on the original rootstock (Camp, 1957), where the scion has overgrown the stock and caused a girdle at the budunion (Day and Schneider, 1952), or where it is desirable to establish a sweet orange root system on a sweet orange/sour orange combination threatened with tristeza.

A number of investigators have reported on methods of inducing scion rooting (Speroni, 1951; Day and Schneider, 1952; Taboada, 1953; Camp, 1957). The method generally used, with slight variations, is to remove small sections of bark, approximately ¼ to ½ inch wide and 1 to 3 inches long, from the scion intermittently around the trunk just above the budunion. Day and Schneider (1952) found that with lemon scions, tangential slices made by chopping through the

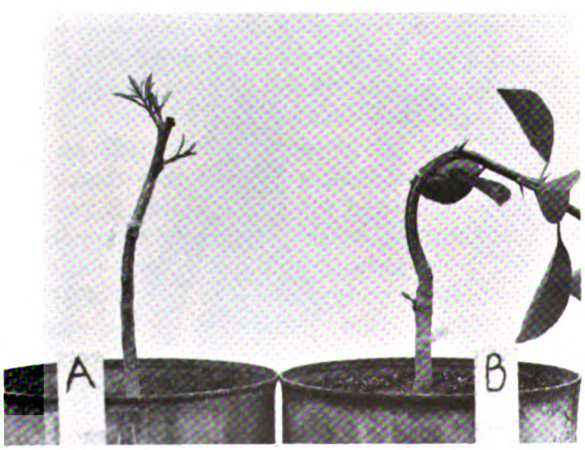

Fig. 1–48. A comparison of tip grafting (*A*) with T budding; (*B*) about 20 days after grafting and budding. (Photo courtesy of California Citrograph.)

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bark and removing some of the wood were equally effective. With either method, approximately one-third to one-half of the trunk is girdled.

The wound is then disinfected with a suitable fungicide to guard against *Phytophthora* infection, and soil is mounded up around the trunk to a height of 3 to 6 inches above the girdle. The mound of soil is then watered thoroughly, and the moisture is maintained by a mulch on the surface. Moisture control is important, since roots will not develop properly if the soil is allowed to dry out. Periodic applications of Bordeaux spray to the trunk and mound of soil will lessen the chances of fungus infection.

New roots should develop within four months and be large enough to support the tree in three to four years.

Tip-Grafted Seedlings

A technique of tip-grafting seedlings used by Richards *et al.* (1963) appears to have advantages in the rapid propagation of container-grown lemon trees under a controlled environment, especially for small lots used in experimental work. Figure 1–48 presents a comparison of tip-grafting and standard budding.

Seed are sprouted in a seedbed. When 6 to 8 inches high, the seedlings are transplanted to individual gallon containers filled with a soil mix. When the seedling stems are approximately pencil size in diameter, they are tip grafted, using a splice graft. The scions are of approximately the same diameter and have two buds. The grafts are wrapped with raffia or rubber bands. About 20 days after grafting, the less vigorous sprout arising from the two buds is rubbed off to allow the other one to grow. Under glasshouse conditions, trees propagated in this manner become large enough to transplant to the orchard within a year after seed is planted.

Trees propagated under such conditions must go through a gradual "hardening-off" period under lath or similar cover before they are set out in the field.

Tissue Culture Propagation

Under the general term of tissue culture propagation, three techniques—embryo culture, nucellus culture, and shoot apex micrografting—have recently been developed to a point of importance in citrus propagation. While all are laboratory techniques, requiring experience, dexterity, and carefully-controlled conditions, they provide methods of obtaining disease-free clones heretofore unobtainable.

Embryo Culture.—Described by Rangan, Murashige, and Bitters (1969) and Bitters, Rangan, and Murashige (1969), embryo culture is a technique in which the development of young citrus seed is manipulated to obtain the desired seedling from polyembryonic species. Highly polyembryonic species and varieties normally produce only nucellar seedlings and hybrids are difficult to obtain. Embryo culture enables the selection and propagation of hybrid embryos. As one example, it provides a means for the development of possibly superior hybrids for rootstocks from species and varieties such as sweet orange, rough lemon, Cleopatra mandarin, Troyer citrange, and Alemow (*C. macrophylla*), all of which are highly polyembryonic.

Nucellus Culture.—Also described by Rangan, Murashige, and Bitters (1969) and Bitters, Rangan, and Murashige (1969), the techniques used in nucellus culture can initiate nucellar embryos true to the parent mother tree in

Fig. 1–49. Seedlings obtained from nucellar embryos of Shaddock (*C. grandis*), a monoembryonic species normally producing only hybrids from zygotic embryos. The seedlings have been 5 months in culture. (Photo by T. Murashige.)

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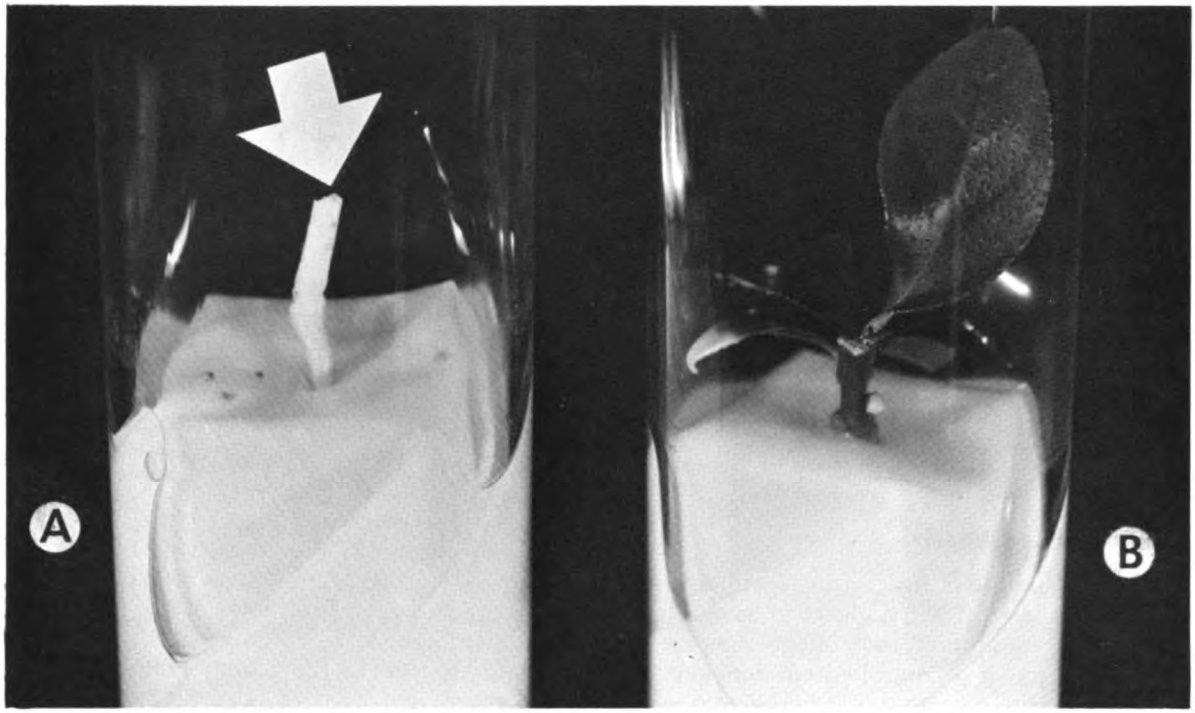

Fig. 1–50. Shoot apex micrografts. *A*, young seedling (rootstock) on which a shoot apex (scion) has been micrografted (arrow indicates location of shoot apex, too small to be visible, on cut surface of rootstock seedling). *B*, the grafted plant 5 months after micrografting. (Photo by T. Murashige).

Fig. 1–51. Trunks of Temple orange plants showing a comparison of thorniness. *A*, an 18-month-old plant produced by shoot apex micrografting. *B*, a 24-month-old plant produced by nucellus culture. (Photo by T. Murashige.)

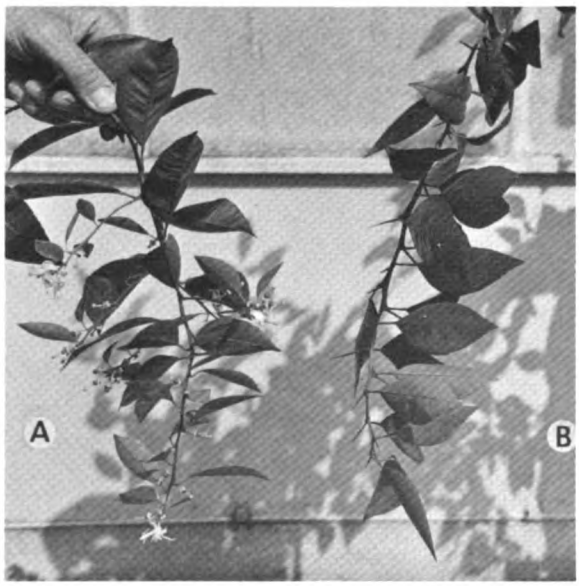

Fig. 1–52. Vegetative shoots from Temple orange plants shown in figure 1–51. *A*, from shoot apex micrograft. *B*, from nucellus culture. Note differences in thorniness and fruit set. Both are free of known virus disease. (Photo by T. Murashige.)

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monoembryonic species and varieties which normally produce only hybrids from zygotic embryos (fig. 1–49). This makes possible the propagation of disease-free clones of such citrus as Meyer lemon, Ponderosa lemon, Temple orange, Clementine mandarin, and Chandler pummelo.

Shoot Apex Micrografting.—Disease-free clones developed from nucellar embryo culture have the disadvantage of remaining in a juvenile stage for a considerable period of time resulting in extreme vigor, excessive thorniness, and a delay in fruit production. To overcome these disadvantages and still obtain virus-free clones, a technique of shoot apex micrografting has been developed (Murashige *et al.*, 1972; Bitters, Rangan, and Murashige, 1969). This technique involves using a dissecting microscope to micrograft the shoot apex from the desired clone onto a very young seedling rootstock (fig. 1–50). The success of the method from the standpoint of obtaining a virus-free clone is based on normal absence of virus in citrus seedlings and on the assumption the shoot apex is also virus-free (see figs. 1–51 and 1–52).

LITERATURE CITED

ALLEN, R. M., and J. B. CARPENTER. 1966. Arizona's cooperative citrus registration-certification program. Plant Dis. Rptr. **50**:145–49.

ALLEN, R. M., and R. B. STREETS. 1961. Bud certification in Arizona. Proc. Second Conf. Intern. Org. Citrus Virol. **1961**:211–15.

ANONYMOUS. 1951. Progress report on "A major operation." Calif. Citrog. **36**:489.

——— 1962. Regulations for registration and certification of citrus trees. Yearbook Calif. Citrus Nurs. Soc. **2**:48–52.

BACCHI, O. 1958. Estudos sôbre a conservação de sementes. II. Citros. Bragantia. **17**:157–66.

BATCHELOR, L. D., and W. P. BITTERS. 1953. Top-working citrus trees. Calif. Citrog. **38**:306, 313, 316, 318.

BEÑATENA, H. N., and A. R. PUJOL. 1965. The citrus budwood program in Concordia, Argentina. Proc. Third Conf. Intern. Org. Citrus Virol. **1965**:241–43.

BIALE, J. B., and F. F. HALMA. 1938. The use of heteroauxin in rooting of subtropicals. Proc. Amer. Soc. Hort. Sci. **35**:443–47.

BITTERS, W. P. 1961. Rootstock responsibilities. Yearbook Calif. Citrus Nurs. Soc. **1**:26–29.

——— 1964. Citrus rootstocks and nursery practices in Japan. Calif. Citrog. **49**:205–10.

BITTERS, W. P., T. MURASHIGE, T. S. RANGAN, E. M. NAUER, C. N. ROISTACHER, and P. B. HOLLIDAY. 1972. Healthy trees from the test tube. Citrograph **57**:85–86, 105.

BITTERS, W. P., T. S. RANGAN, and TOSHIO MURASHIGE. 1969. Nucellar and hybrid seedlings derived from tissue culture. Calif. Citrog. **54**:139–41, 161–62.

BLONDEL, L. 1952. Technique du regreffage des agrumes. Fruits Primeurs Afr. Nord. **22**:244–50.

BOTHAM, J. R. 1957. A pictorial guide to propagating citrus trees. Jour. So. Austral. Dept. Agr. **61**(5): 245–50.

BRIDGES, G. D., C. O. YOUTSEY, and R. R. NIXON, JR. 1965. Observations indicating psorosis transmission by seed of Carrizo citrange. Proc. Fla. State Hort. Soc. **78**:48–50. (Also Yearbook Calif. Citrus Nurs. Soc. **5**:33–36.)

BRUN, J. 1953. La fonte des semis de bigaradiers (*Sclerotinia* sp.). Fruits Outre Mer. **8**:118–19.

CAHOON, G. A., E. S. MORTON, B. W. LEE, and G. E. GOODALL. 1963. The use of plastic ground covers in citrus nurseries. Proc. Amer. Soc. Hort. Sci. **83**: 309–15.

CAMERON, J. W., R. K. SOOST, and H. B. FROST. 1959. The horticultural significance of nucellar embryony in citrus. *In:* Wallace, J. M. (ed.). Citrus virus diseases. Pp. 191–96. Univ. Calif. Div. Agr. Sci., Berkeley.

CAMP, A. F. 1950. Citrus propagation. Univ. Fla. Agr. Ext. Serv. Bul. **139**:48 pp.

——— 1957. Citrus propagation. *In:* Citrus industry of Florida. Pp. 48–99. Fla. Dept. Agr., Tallahassee.

CHANDLER, W. H. 1958. Evergreen orchards. Third edition. Lea and Febiger, Philadelphia. 535 pp.

CHAPOT, H. 1955. Remarques sur la germination des pépins de *Poncirus trifoliata* (Rafin). Fruits Outre Mer **10**:165–68.

CHILDS, J. F. L., and G. HRNCIAR. 1948. A method of maintaining viability of citrus seed in storage. Proc. Fla. State Hort. Soc. **61**:64–69.

CHILDS, J. F. L., and R. E. JOHNSON. 1966. Preliminary report of seed transmission of psorosis virus. Plant Dis. Rptr. **50**:81–83.

COOPER, W. C., and K. R. KNOWLTON. 1940. The effect of synthetic growth substances on the rooting of subtropical fruit plants. Proc. Amer. Soc. Hort. Sci. **37**:1093–98.

DAY, B. E., and H. SCHNEIDER. 1952. Stimulation of roots above overgrown lemon buds. Calif. Citrog. **38**:46, 58.

DEAN, R. H. 1963. The use of water sprinklers for protection of citrus nursery trees against freeze damage. Citrus Indus. **44**(8):14–16, 22.

DILLON, F. C., F. REAL, and D. F. DILLON. 1962. Simultaneous grafting and rooting of citrus under mist. Comb. Proc. 12th Ann. Mtg. East Region and 3d Ann. Mtg. West Region Plant Prop. Soc. Pp. 229–33.

DOMATO, J., and H. S. ARAMAYO. 1953. Conducción de almácigos de portainjertos citricos. Idia [Buenos Aires] **71**:21–26.

DURBIN, R. D. 1959. The possible relationship between *Aspergillus flavus* and albinism in citrus. Plant Dis. Rptr. **43**(8):922–23.

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ELZE, D. L. 1949. Germination of citrus seed in relation to certain nursery practices. Palestine Jour. Bot. [Rehovot] 7:69–80.

ERICKSON, L. C., and W. P. BITTERS. 1953. Effects of various plant-growth regulators on rooting of cuttings of citrus and related species. Proc. Amer. Soc. Hort. Sci. 61:84–88.

FORD, H. W. 1957. A method of propagating citrus rootstock clones by leaf bud cuttings. Proc. Amer. Soc. Hort. Sci. 69:204–07.

FORD, H. W., and W. A. FEDER. 1961. Additional rootstock selections that tolerate the burrowing nematode. Proc. Fla. State Hort. Soc. 74:50–53.

FROST, H. B. 1948. Genetics and breeding. *In:* Webber, H. J., and Batchelor, L. D. (eds.). The citrus industry. I:817–913. Univ. Calif. Press, Berkeley and Los Angeles. (*See specifically:* pp. 825–29, 835–37.)

FU, W. H. 1951. Germination and storage of trifoliate orange seeds. Calif. Citrog. 37:38–39.

FURR, J. R. 1961. Earliness of flowering and fruiting of citrus trees propagated from top and basal shoots of young fruiting seedlings. Jour. Rio Grande Val. Hort. Soc. 15:44–49.

GARNSEY, S. M., and J. W. JONES. 1967. Mechanical transmission of exocortis virus with contaminated budding tools. Plant Dis. Rptr. 51:410–13.

GERBER, J. F., and C. H. HENDERSHOTT. 1963. Overhead sprinkler irrigation for cold protection, field trials. Proc. Fla. State Hort. Soc. 76:86–91.

GONZALEZ, L. G., and C. R. CASAL. 1950. Topworking pummelo trees by graftinarching. Philipp. Agr. 33:278–84.

HALMA, F. F. 1931. The propagation of citrus by cuttings. Hilgardia 6(5):131–57.

——— 1933. Size and age of budwood in relation to size of yearling citrus. Proc. Amer. Soc. Hort. Sci. 30: 373–74.

——— 1947. Own-rooted and budded lemon trees. Calif. Citrog. 33:1–2, 14–15.

HALMA, F. F., and K. W. OPITZ. 1952. Observations on foot rot of orange trees. Calif. Citrog. 38:41.

HALSEY, D. D. 1966. Aluminum foil tubes useful around citrus seedlings. Yearbook Calif. Citrus Nurs. Soc. 5:69–70.

HORANIC, G. E., and F. E. GARDNER. 1958. Effects of subfreezing temperatures on the viability of citrus seeds. Proc. Fla. State Hort. Soc. 71:79–81.

JOHNSTON, J. C., K. W. OPITZ, and E. F. FROLICH. 1959. Citrus propagation. Univ. Calif. Coll. Agr. Circ. 475: 23 pp.

KLEINSCHMIDT, G. D., and J. W. GERDEMANN. 1972. Relationship of endomycorrhizae to citrus stunting in fumigated soils. [Abstr.] Phytopathology 62(7):769.

KLOTZ, L. J., T. A. DEWOLFE, D. A. NEWCOMB, and R. G. PLATT. 1966. Control of damping-off of citrus seedlings. Calif. Citrog. 51:314, 322, 324.

KLOTZ, L. J., T. A. DEWOLFE, C. N. ROISTACHER, E. M. NAUER, and J. B. CARPENTER. 1960. Heat treatments to destroy fungi in infected seeds and seedlings of citrus. Plant Dis. Rptr. 44:858–61. (*Also:* Calif. Citrog. 46:63–64.)

KNOWLTON, C. S. 1959. Successful inarching. Calif. Citrog. 44:110, 128–29.

LARUE, R. G. 1950. Stump grafting of citrus. Calif. Citrog. 35:182–83, 202.

——— 1953. Scions used in stump grafting. Calif. Citrog. 38:404–05.

MCCOWN, J. T. 1959. Citrus nursery practices. Univ. Fla. Agr. Ext. Serv. Circ. 198: 15 pp.

MAITI, R. G., S. M. SINGH, and I. J. SINGH. 1959. Effects of type of scion buds and plant regulators on the success of bud grafting in grapefruit (*Citrus paradisi* Macf.) Indian Jour. Hort. 16:149–52.

MARTIN, J. P. 1949. Growth of citrus seedlings in old citrus soils. Calif. Citrog. 34:102, 110–11.

——— 1962. Possible temporary growth inhibition following soil fumigation for citrus seedlings. Yearbook Calif. Citrus Nurs. Soc. 2:25–26.

MARTIN, J. P., R. C. BAINES, and A. L. PAGE. 1963. Observations on the occasional temporary growth inhibition of citrus seedlings following heat or fumigation treatment of soil. Soil Sci. 95:175–85.

MARTIN, J. P., and A. L. PAGE. 1962. Influence of pH on growth and chemical composition of seedlings. Calif. Citrog. 48:2–3, 21–22.

MATHER, S. M. 1963. Registration and certification of citrus trees in California. Calif. Citrog. 48:188, 214–17.

MATKIN, O. A., and P. A. CHANDLER. 1957. The U. C.-type soil mixes. *In:* Baker, K. F. (ed.). The U. C. System for producing healthy container-grown plants. Univ. Calif. Div. Agr. Sci. Manual 23:68–85.

MENDEL, K. 1936. The anatomy and histology of the bud union in citrus. Palestine Jour. Bot. Hort. Sci. 1:13–46.

——— 1937. Some considerations on the anatomy and physiology of citrus budding. Hadar [Tel-Aviv] 10:60–64.

MONSELISE, S. P. 1953. Viability tests with citrus seeds. Palestine Jour. Bot. [Rehovot] 8:152–57.

MONTENEGRO, H. W. S., and A. A. SALIBE. 1960. Conservacao de sementes de porta-enxertos para citrus. Rev. Agr. [Piracicaba] 35:109–35.

MOORE, P. W. 1961. Treatment and storage of citrus seed and budwood. Yearbook Calif. Citrus Nurs. Soc. 1:19–21.

MUNGOMERY, W. V., G. W. AGNEW and E. T. PRODONOFF. 1966. Maintenance of citrus seed viability. Queensland Jour. Agr. Anim. Sci. 23(2):103–20.

MURASHIGE, T., W. P. BITTERS, T. S. RANGAN, E. M. NAUER, C. N. ROISTACHER, and P. B. HOLLIDAY. 1972. A technique of shoot apex grafting and its utilization towards recovering virus-free citrus clones. HortScience 7:118–19.

NAUER, E. M., E. C. CALAVAN, C. N. ROISTACHER, R. L. BLUE and J. H. GOODALE. 1967. The citrus variety improvement program in California. Calif. Citrog. 52:133, 142, 144, 146.

NAUER, E. M., and J. H. GOODALE. 1964. Forcing newly budded citrus. Calif. Citrog. 49:294–97.

NAUER, E. M., and C. N. ROISTACHER. 1962. Long term storage of heat treated citrus seed. Calif. Citrog. 47:140.

NEWCOMB, D. A. and D. L. HENDRICKSON. 1966. A citrus seed heat treating procedure for handling large volumes of seed. Yearbook Calif. Citrus Nurs. Soc. 5:53–55.

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NORMAN, G. C. 1959. Florida State Plant Board program for virus-free budwood. *In:* Wallace, J. M. (ed.). Citrus virus diseases. Pp. 237–42. Univ. Calif. Div. Agr. Sci., Berkeley.

OLSON, E. O. 1954. A crown rot of citrus rootstock seedlings caused by *Sclerotium rolfsii*. Proc. Rio Grande Val. Hort. Inst. 8:29–31.

OPITZ, K. W. 1951. Troyer citrange rootstock propagation. Calif. Citrog. 36:454, 456.

——— 1960. Warning on citrus budwood. Western Fruit Grow. 14(1):33.

——— 1961. Guide to top-working. Calif. Citrog. 46:320.

OPITZ, K. W., R. G. PLATT and E. F. FROLICH. 1968. Propagation of citrus. Univ. Calif. Coll. Agr. Circ. **546**: 25 pp.

OPPENHEIM, J. D. 1932. A new system for layers. Hadar [Tel-Aviv] 5(1):2–4.

PERLBERGER, J., and I. REICHERT. 1938. Experiments on the control of albinism in citrus seedlings. Bul. Palestine Agr. Res. Sta. [Rehovot] 24:40–77.

PLATT, R. G. 1956. A look at rootstocks for Ventura. Calif. Citrog. 41:216–18.

——— 1959. Pros and cons of topworking. Calif. Citrog. 44:355, 367–68.

——— 1967. A method of citrus propagation—microbudding. Yearbook Calif. Citrus Nurs. Soc. 6:26–28.

PUJOL, A. R. and H. N. BEÑATENA. 1965. Study of psorosis in Concordia, Argentina. Proc. Third Conf. Intern. Org. Citrus Virol. 1965:170–74.

RANGAN, T. S., TOSHIO MURASHIGE, and W. P. BITTERS. 1969. In vitro studies of zygotic and nucellar embryogenesis in citrus. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. 1:225–29. Univ. of Calif. Riverside, Calif.

REID, R. D. 1955. Nursery method speeds growing time. Calif. Citrog. 40:318–19.

RICHARDS, A. V. 1952. Viability of citrus seeds. Trop. Agr. 108(3):186–88.

RICHARDS, S. J., M. K. HARJUNG, J. E. WARNEKE, and W. W. HILLIS. 1963. Unique procedures employed in growing lemon trees. Calif. Citrog. 48:96–99.

RICHARDS, S. J., P. W. MOORE, and J. E. WARNEKE, 1967. Growing citrus in soil containers. Calif. Citrog. 52: 339–40, 342–45.

ROHRBAUGH, P. W. 1957. Watch those citrus cycles. Texas Farm. and Citricult. 33(7):6.

ROISTACHER, C. N., and E. M. NAUER. 1961. A quick test for citrus seed viability. Calif. Citrog. 46:300–02.

——— 1962. A quick test for citrus seed viability. Univ. Calif. Agr. Expt. Sta. Ext. Ser. Leaf. 138:5 pp.

ROSSETTI, V., A. A. SALIBE, A. F. CINTRA, S. BONILHA, and D. ARMBRUSTER. 1965. The citrus budwood registration program in the state of São Paulo, Brazil. Proc. Third Conf. Intern. Org. Citrus Virol. 1965:235–40.

RYAN, G. F., and E. F. FROLICH. 1961. Preparation and storage of citrus seed. Yearbook Calif. Citrus Nurs. Soc. 1:17–18.

RYAN, G. F., E. F. FROLICH, and T. P. KINSELLA. 1958. Some factors influencing rooting of grafted cuttings. Proc. Amer. Soc. Hort. Sci. 72:454–61.

RYAN, G. F., G. GREENBLATT, and K. A. AL-DELAIMY. 1961. Seedling albinism induced by an extract of *Alternaria tenuis*. Science 134:833–34.

RYAN, G. F., and E. STEIN. 1958. Albinism in citrus seedlings. Calif. Citrog. 43:293–95.

SAID, M., and G. F. RYAN. 1961. Fungicidal treatment of citrus seed. Calif. Citrog. 46:125, 127.

SCHNEIDER, H., and J. M. WALLACE. 1954. Tests on orange trees topworked to lemons. Calif. Citrog. 39:224, 248–52.

SHANNON, L. M., E. F. FROLICH, and S. H. CAMERON. 1960. Characteristics of *Poncirus trifoliata* selections. Proc. Amer. Soc. Hort. Sci. 76:163–69.

SLEETH, B. 1959. The budwood certification program in Texas. *In:* Wallace, J. M. (ed.). Citrus virus diseases. Pp. 233–35. Univ. Calif. Div. Agr. Sci., Berkeley.

SOOST, R. K., J. W. CAMERON, W. P. BITTERS, and R. G. PLATT. 1961. Citrus bud variation—old and new. Calif. Citrog. 46:176, 188, 190–93.

SPERONI, H. A. 1951. El afrancamiento de las plantas citricas enfermas de "tristeza." Idia [Buenos Aires] 45:18–20.

SUTTON, N. E. 1954. Marcotting of Persian limes. Proc. Fla. State Hort. Soc. 67:219–20.

TABOADA, V. L. 1953. Afrancamientos en plantas injertadas sobre naranjo agrio en le provincia de Tucumán. Idia [Buenos Aires] 71:11–12.

TAGER, J. M., and S. H. CAMERON. 1957. The role of the seedcoat in chlorophyll deficiency (albanism) of citrus seedlings. Plant Physiol. 10:302–05.

TATE, H. F. 1954. Topworking citrus and other trees. Ariz. Univ. Agr. Ext. Serv. Circ. 220:19 pp.

TORRES, J. P. 1936. Polyembryony in citrus and study of hybrid seedlings. Philipp. Jour. Agr. 7:37–58.

VAN DER MEULEN, A., E. F. MALAN, and C. J. NAUDÉ. 1954. Citrus propagation. Farming So. Africa 29: 487–92.

WATKINS, J. V., and G. H. BLACKMON. 1939. Leaf-bud cuttings for multiplying tropical shrubs. Proc. Amer. Soc. Hort. Sci. 37:1109–11.

WEATHERS, L. G., and E. C. CALAVAN. 1959. Nucellar embryony—a means of freeing citrus clones of viruses. *In:* Wallace, J. M. (ed.). Citrus virus diseases. Pp. 197–202. Univ. Calif. Div. Agr. Sci., Berkeley.

WEBBER, H. J. 1948*a*. Nursery methods. *In:* Batchelor, L. D., and H. J. Webber (eds.). The citrus industry. II:1–68. Univ. Calif. Press, Berkeley and Los Angeles. (*See specifically:* pp. 24–28.)

——— 1948*b*. Plant characteristics and climatology. *In:* Webber, H. J., and L. D. Batchelor (eds.). The citrus industry. I:41–69. Univ. Calif. Press, Berkeley and Los Angeles.

WEINDLING, R., and H. S. FAWCETT. 1936. Experiments in the control of *Rhizoctonia* damping-off of citrus seedlings. Hilgardia 10:1–16.

WISHART, R. L. 1961. Microbudding of citrus. So. Austral. Dept. Agr. Leaf. 3660:10 pp.

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CHAPTER 2

Planning and Planting the Orchard

ROBERT G. PLATT

ESTABLISHMENT OF A SUCCESSFUL citrus orchard requires careful planning before the first tree is set in the ground. In addition, the selection of trees, the planting approach chosen, and the care of the orchard during its first years are critical. Citrus trees, like most other tree crops, have a life expectancy of several decades. Once trees are planted, careless decisions on orchard location, orchard layout, or variety are not easily corrected. Sometimes correction is impossible. Even if modifications can be made, they are often costly and seldom completely satisfactory. Thus, proper planning before planting, together with the choice of variety, planting system selected, and care given young trees, is of great importance in a successful and profitable citrus-growing enterprise.[1]

PLANNING THE ORCHARD

Many factors influence the choice of orchard location. Each factor should be weighed individually and in combination with others before making a final decision. In California, it has been long recognized that the three basic requirements for a satisfactory orchard site are (1) a climate relatively free from temperature and wind hazards; (2) an adequate supply of good quality water for irrigation; and (3) a reasonably deep and fertile uniform soil, which has good internal drainage (Platt, 1966). In many citrus-growing areas, there are subsidiary factors of a regional nature to be considered. In parts of Florida and in various countries where excessive rainfall occurs at certain times of the year, an additional requirement is a site with good surface drainage or one that permits adequate removal of excess water (Lawrence, 1962). In Arizona or other arid regions where flood irrigation is practiced, citrus sites should be on land that can be graded properly (Hilgeman and Rodney, 1961).

Other factors to be considered in planning an orchard include the economic outlook and adaptability of the citrus variety chosen, availability of labor, proximity of the orchard to packing or processing facilities, land and water costs, and taxes. The basic requirements, of course, are essential to growing a satisfactory crop, but these latter factors may be of equal importance in site selection.

At times, a location under consideration will be deficient in terms of the basic factors. In addition, few locations are ever completely satisfactory in terms of the other factors. In practice, a site is usually selected as the result of a compromise between several desirable factors and one or two less desirable ones. Windbreaks, for example, may be used to reduce wind damage, and frost protection may be provided in cold locations. Where modification of one factor is necessary, however, other factors should offer distinct advantages that outweigh the added costs for modification and the need for more management ability.

The various factors involved in selection of a suitable orchard site are discussed individually below. More extensive coverage of the basic factors may be found in Chapters 4, 8, 9, and 10, which deal with soils, irrigation, climate, and frost protection, respectively.

[1] Important references on planning and planting the orchard not specifically cited in the text include: Parker (1948); LaRue and Rounds (1948); and Opitz and Platt (1969).

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Climate

Of the three basic requirements—suitable climate, good soil, and water availability—climate is the most important factor in site selection in most citrus-growing regions of the world. Climate is the primary determinant of where citrus can exist, and the quality of fruit produced, whereas soil and water determine crop productivity or yield. Beyond certain limits, the losses of trees or crops or the impaired quality of fruit resulting from adverse weather are so great that the production of all citrus fruits becomes impossible or unprofitable. In older, well-established citrus-growing regions, the general boundaries that are suitable have been established in some cases by experience gained through trial and error. Even within any established region, however, there are local areas entirely unsuitable for citrus or suited for certain varieties only. Similarly, there are local areas outside the boundaries of established regions where the climate may be entirely suitable for some or all citrus varieties.

Of the various aspects of climate, freezing temperatures are most limiting to citrus production. For some varieties, however, high temperatures must be considered, since excessive heat limits productivity and may damage fruit. Wind must also be taken into consideration. Winds of high velocity or chilling winds from an ocean can cause tree damage, reduced growth, loss of fruit, and lower fruit quality.

To determine the suitability of any area or plot of land where little is known about the climate, a wise investment in both time and money is installation of instruments to determine actual temperatures for a season or two before the final decision to plant. These observations compared with those from other areas where citrus is grown will be a factor not only in deciding on the advisability of planting but also in determining which variety or varieties are best suited to the area. It should be recognized that minimum temperatures in bare, unplanted fields are often two to four degrees *warmer* than the same location after trees are planted and air drainage is restricted.

Low Temperature Hazards.—Frosts or freezes occur in most of the larger commercial citrus-producing areas of the world. In such areas, the frequency, severity, and duration of temperatures below the freezing point are of critical importance in the selection of a site. Although they may be costly to the grower, moderate freezes or frosts are usually not disastrous, since they injure only the leaves or the crop on the tree. Serious freezes kill branches of trees and may result in crop losses for several years. Repeated at frequent intervals, serious freezes will permanently damage trees. Severe freezes may result in the death of trees.

Fig. 2–1. Effect of elevation on cold temperatures and tree damage. Young trees (light-colored) in the depression have been frozen, while those farther up the slope and on the hilltop are not damaged. (Photo by F. M. Turrell.)

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Air drainage.—Frosts, sometimes referred to as light freezes, often involve air becoming chilled when it comes in contact with the cold, exposed surfaces of vegetation and soil which have radiated their heat to the open night sky. This cold air, being heavier and flowing in much the same manner as water, seeks low elevations, where, if there is no outlet, it "pools up" and forms cold pockets. Under different topographical conditions, these cold pockets may vary in size from small areas of less than an acre to several hundred or thousand acres on the floor of a large valley. Even on broad, uniform slopes, a flat area or bench well above the floor of a valley may slow down air movement sufficiently to create cold pockets. Similarly, cold pockets may be caused by a solid row of windbreak trees, an earth fill, or any obstruction to the natural flow of air.

It is therefore important to select an orchard site with topography which provides adequate air drainage so that cold air can easily move away. Otherwise, additional frost protection is usually necessary in these cold pockets.

The actual differences in elevation necessary to provide air drainage, and thus create warmer orchard temperatures, are not great. Lawrence (1962) reports that in southern Florida an elevation difference of as little as four to five feet above a surrounding area can cause an increase of from 2° to 5° F on calm, clear, cold nights. Nelson (1940) also reported increases of 5° F in temperature for a 10-foot increase in elevation, and of 13° F for an 88-foot increase.

In the more irregular topography of California, temperature differences at different elevations are often striking. It is not uncommon, following severe frosts, to find trees in hilly topography badly frozen at the lower part of an orchard and sustaining little or no damage at higher elevations (fig. 2–1).

Advection freezes, on the other hand, are a different matter. When these occur, normally accompanied by considerable wind, high ground may be as cold or colder than low ground. Bailey *et al.* (1963) pointed out that in the Rio Grande Valley of Texas citrus on higher land or ridges is subjected to warmer temperatures during radiation frosts but to colder temperatures during advection freezes.

Advective freezes are usually infrequent, so the best site in areas where frosts and freezes are a hazard is one with adequate air drainage.

Elevation.—The actual elevation above sea level at which citrus will grow successfully is usually less important, within limits, than the elevation of immediately adjacent lands. Under ideal conditions, temperature decreases about 1.6° F for each 300-foot increase in elevation (Young, 1940), making citrus culture at high elevations less adaptable because of lower temperatures.

In most of the commercial citrus-producing areas of the world, citrus is grown at relatively low elevations. In California, for example, successful orchards are located from elevations of 230 feet below sea level to approximately 2,000 feet.

The effects of latitude, however, allow higher elevations to be used successfully nearer the equator. Nearly all citrus produced in the state of São Paulo, Brazil, is at an elevation of over 2,000 feet (Burke, 1958), and oranges in southern Rhodesia are grown at elevations of 4,000 to 6,000 feet.

Bodies of water.—The ability of bodies of water to store heat and release it during cold periods has considerable influence on adjacent orchard temperatures, and should be used to advantage, where feasible, in site location. This is well illustrated by the frost protection afforded citrus orchards located adjacent to and on the south and southeast side of lakes in Florida. (See chap. 10, p. 429.) Freezing air masses blown by northwest winds are warmed as they pass over the lakes and their effect is often evident up to a mile from the water. The larger and deeper the body of water, the greater the effect, although a number of smaller, deep lakes may afford even greater protection (Lawrence, 1958). The coastal districts of California and other maritime citrus-producing areas receive similar benefit from the moderating influence on freezing temperatures of an ocean.

High Temperature Hazards.—Most varieties of citrus tolerate relatively high temperatures, but abrupt increases of temperature to higher-than-normal levels or extreme temperatures accompanied by low relative humidity are often injurious. Young fruits and leaves are particularly sensitive.

The damage caused by an abrupt temperature increase is relative to the temperatures just preceding the sudden rise and the time of year the increase occurs. In the interior valleys of California, it has long been observed that before the soil warms up in the spring, a sudden increase in air temperature will result in leaf drop followed by twig dieback two or three months later. Since roots are not actively functioning when soil tem-

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perature is below 55° F, it is reasoned that the increased water loss from the tree through transpiration caused by the higher air temperature is greater than an inactive root system in cold soil can replenish (Klotz *et al.*, 1962).

From the standpoint of crop loss, abrupt increases to temperatures considerably higher than normal are most damaging if they occur during and just after the period of fruit set. Sudden extreme increases in temperature during this period may result in a complete crop loss. The injurious effects are greatly increased if the soil is dry or the abrupt high temperatures are accompanied, as they often are in semiarid areas, by desiccating winds (Platt, 1958).

In areas of extreme summer temperatures, heat damage in the form of sunburned peel, dried flesh, reduced fruit size, and increased granulation is often found on fruit exposed to the sun (Ketchie and Furr, 1968). In a study of Valencia orange fruit in California's Coachella Valley, Ketchie and Ballard (1968) found that damage occurred when average air temperatures were 112° F and relative humidity 20 per cent. No damage occurred when average air temperatures were 105° F, fruit center temperatures 95° F, and relative humidity 30 per cent. Shaded fruit in periods of damaging temperatures were not injured.

Some citrus varieties have a greater ability to withstand high temperatures than other varieties. Valencia oranges, grapefruit, lemons and most mandarins, for example, produce well in areas of high temperatures, although under extreme temperatures exposed fruit may be damaged. Navel oranges or satsuma mandarins, on the other hand, are apt to be poor producers when high temperatures occur during the bloom and fruit set period.

Attempts have been made to modify the effects of abrupt high temperatures and thus reduce crop losses. Overhead sprinklers, operated during periods of damaging maximum temperatures, have reduced orchard temperatures by 10° to 15° F (Schade, 1966). The use of such a method, however, is limited to orchards where overhead sprinkling is feasible.

Mean Temperatures and Varieties.—The mean temperature of an area, within the limits of minimum and maximum temperatures, must also be considered in the selection of an orchard site for citrus. It has a decided bearing on which varieties will be commercially feasible and determines the yield, season of maturity, and fruit quality of the varieties chosen (see chap. 9).

The several distinct climatic zones in California illustrate the performance of different citrus varieties from the standpoint of mean temperatures. Lemons, for example, are grown successfully in all zones from the coast to the desert, but wide differences exist in season of production. Lemons grown in coastal districts are nearly everbearing, while those grown in the hot interior valleys and desert valleys mature one crop in the fall and early winter. Valencia oranges have a wide range of adaptability, and fruit of acceptable to high quality is produced in all but the extreme coastal zones.

Navel oranges, on the other hand, require relatively high mean temperatures for best quality and are produced in the warm interior valleys. Yields and quality of navel oranges in some desert valleys, however, are not satisfactory so they are a poor choice for such regions.

Grapefruit, like navel oranges, require high mean temperatures, but unlike navel oranges their fruit quality and yields are best in the hot desert valleys. In the interior and intermediate valleys with lower mean temperatures, grapefruit produce well, but quality is somewhat poorer. The fact that grapefruit in these areas of lower mean temperatures mature later, however, is often an advantage in marketing.

Wind.—Wind can have a definite limiting effect on citrus production and must be considered in choosing a location (Botham, 1963; Platt, 1966). Four general types of winds are recognized as being of concern to citrus production in different regions of the world.

One is the hot, dry, and often violent wind technically called "foehn" wind. In California, these winds, usually occurring in the spring or fall, are known locally as "Santa Anas," "santanas," "northers," or "easters," depending on the area. In the Mediterranean basin, they are referred to as "siroccos" or "khamseens." These winds, often averaging 35 miles per hour with gusts up to over 50 miles per hour, cause varying amounts of damage to trees and fruit. They are usually characterized by low humidity and high temperature because of dynamic compression accompanying their origin (Young, 1933). Metcalf (1936) observed that winds from 15 to 20 miles per hour cause some fruit scarring, at 25 to 30 miles per hour some mature fruit is shaken off trees, and at 30 to 40 miles per hour most mature fruit will be on the ground in unprotected orchards. Reed

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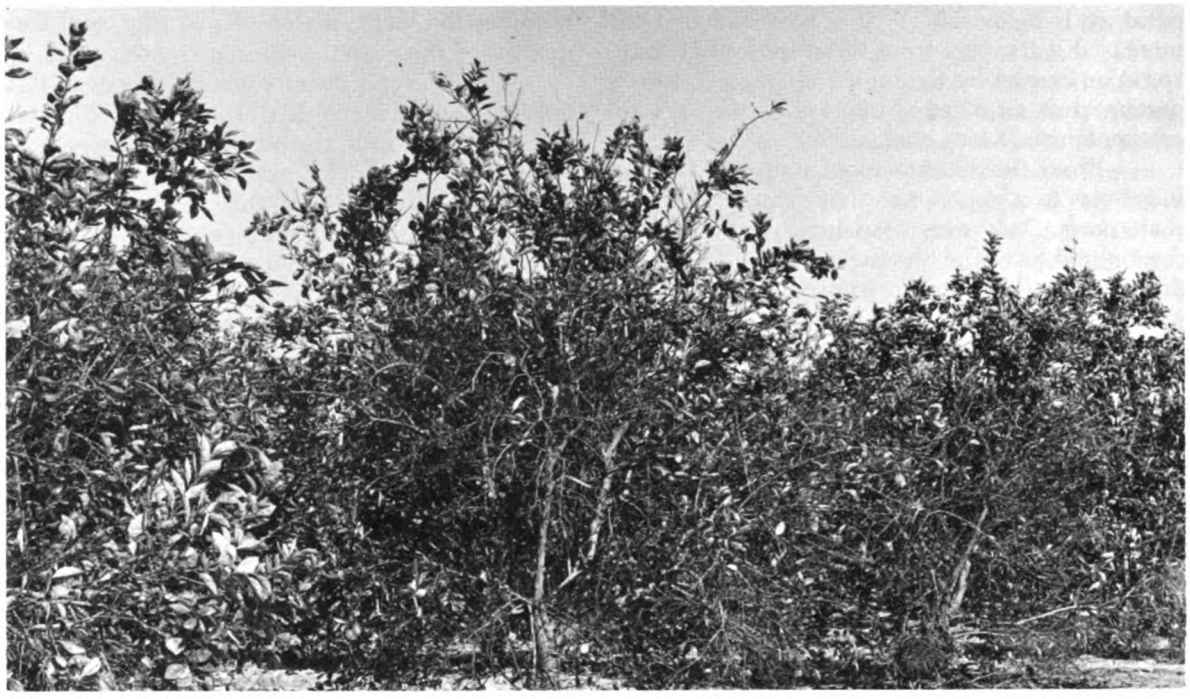

Fig. 2–2. Defoliation of navel orange trees caused by strong winds on the exposed side of an orchard without protective windbreaks.

and Bartholomew (1930) noted additional damage in the form of desiccation and scorch of leaves and the extensive death of small twigs. This is due not so much to velocity but to the high temperature and low humidity often associated with these winds. Such damage causes a weakening of the tree and substantial loss of the subsequent crop (fig. 2–2).

A second type of wind is the prevailing wind of low to moderate velocity which blows so continuously that young trees grow lopsided. Mature trees normally have enough structural strength to withstand damage from these winds, although some lowering of external fruit quality on exposed trees may result from scarring.

The third type of wind is the prevailing and chilling wind of low to moderate velocity that blows from the ocean in certain coastal districts. Temperature rather than velocity is the limiting factor of these winds. Their chilling effect inhibits normal growth up to five miles from the coast, and the author has observed newly planted and unprotected lemon trees killed because of the growth suppression effect of these winds.

Winds associated with hurricanes and typhoons occasionally do severe damage to citrus in areas where these disturbances occur. Because of their overpowering velocity, however, it is difficult, if not impossible, to protect trees against them. In selecting a site, it is wise to consider the frequency of such winds before investing in an orchard.

In areas subjected to winds damaging to tree growth, yield, and fruit quality, the decision must be made as to whether or not planting citrus is justified. If other factors are favorable and outweigh occasional damage by wind, such damage can often be reduced to acceptable levels by the use of windbreaks (Platt, 1966).

Effectiveness of windbreaks.—The effectiveness of windbreaks under all but the most severe conditions has been well demonstrated. Young (1926, 1927) showed that wind velocities were reduced 45 to 59 per cent in the lee of 70- to 90-foot tall windbreaks (table 2–1). In comparisons of the effectiveness of windbreaks on yield and fruit quality, Metcalf (1936) showed substantial benefit from windbreak protection (table 2–2).

In protecting against prevailing and chilling winds from the ocean, Blanchard (1934) found a five to sevenfold increase in the yield of windbreak-protected Eureka lemon trees planted two

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Table 2–1
COMPARISON OF WIND VELOCITIES NEAR VILLA PARK, ORANGE COUNTY, CALIFORNIA*

	Station 1† (Mph)	Station 2‡ (Mph)	Decreased Velocity Due to Windbreak (Per Cent)
Trials During Fall of 1925			
Maximum velocity (5-minute period)	27	15	45
Average hourly maximum velocity for 24 hours	15	6.5	57
Average hourly wind movement for 24 hours	12	5.5	54
	Station 1 (Mph)	Station 2§ (Mph)	Decrease Due to Windbreak (Per Cent)
Trials During Fall of 1926			
Maximum velocity (5-minute period)	29	13	55
Average hourly velocity for 30-hour period	18	8	56
Average hourly maximum for 30-hour period	22	9	59

Source: Young (1926, 1927).
* Instruments placed 18 feet above ground or about 2 feet above tree tops.
† Station No. 1: Middle of large unprotected citrus orchard.
‡ Station No. 2 (1925): 165 feet in lee of 70- to 90-foot windbreak.
§ Station No. 2 (1926): 310 feet in lee of same windbreak.

to five miles from the coast in Ventura County, California (table 2–3). He also observed that protected trees had twice the top volume of unprotected trees of the same age, as well as more vigor, better color, and larger leaves.

Evaporation and transpiration losses are also reduced by windbreaks. Bates (1924) found that as much as a 65 per cent reduction of evaporation occurred in the immediate lee of the most effective windbreaks.

Disadvantages of windbreaks.—While the value of windbreaks in windy areas has been well demonstrated, there are certain disadvantages in their use. Competition with orchard trees for water and nutrients, shading, formation of "cold pockets," the possible harboring of insect pests, and inconvenience to cultural operations all contribute to making windbreaks what often have been called "necessary evils." The inclusion of windbreaks in an orchard planting also reduces the amount of land which can be planted to citrus.

The effects of windbreak competition on the yield of 25-year-old lemon trees was illustrated by Lombard (1950*a*). In a five-year trial, he recorded the yield of successive rows of lemon trees as the distance from a large blue gum windbreak increased (table 2–4). It should be noted that no root pruning was done on windbreak trees and that eucalyptus roots were found as far as 160 feet from the windbreak. Where windbreaks

Table 2–2
YIELD AND PACKOUT OF CITRUS IN PROTECTED AND UNPROTECTED CALIFORNIA ORCHARDS

Fontana Area (Inland Valley)	Protected	Partly Protected
Yield per acre (lb)	13,200	10,640
1st grade (per cent of yield)	67.6	50.9
2nd grade (per cent of yield)	16.4	15.5
3rd grade (per cent of yield)	9.7	12.1
Culls (per cent of yield)	6.3	18.0
2nd grade (per cent of yield)	24.9	31.0
Windfalls (per cent of yield)	0	3.5
Dollar value of fruit per acre	506.88	271.28
Yorba Linda Area (Coastal)	**Protected**	**Unprotected**
Yield per acre (fld. bxs.)	585	188
1st grade (per cent of yield)	40.3	23.6
3rd grade (per cent of yield)	14.5	8.5
Culls (per cent of yield)	18.0	37.0

Source: Adapted from Metcalf (1936).

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Table 2–3
DEPRESSING EFFECT OF WIND ON YIELD OF EUREKA LEMON TREES NEAR OXNARD, VENTURA COUNTY, CALIFORNIA

	Tree No.	Protected (Number Fruits Per Tree)	Unprotected (Number Fruits Per Tree)
Orchard No. 1	1	1017	94
(9-year-old Eureka	2	500	120
lemons, 2 miles	3	761	77
from ocean)	4	590	97
Average		717	97
Orchard No. 2	1	544	65
(4-year-old Eureka	2	224	79
lemons, 5 miles	3	386	13
from ocean)	4	170	81
	5	120	37
Average		288	55

Source: Blanchard (1934).

Table 2–4
EFFECT OF DISTANCE FROM WINDBREAK ON LEMON PRODUCTION IN CALIFORNIA; BASED ON AVERAGE PRODUCTION PER ACRE PER YEAR FOR FIVE YEARS (CONVERTED FROM ONE-HALF-ACRE ROWS)

Row No.	Distance from Windbreak (Feet)	Pounds of Fruit Per Acre
1	23	18,124
2	45	23,460
3	67	28,060
4	89	31,464
5	111	34,500
6	133	35,604
7	155	37,260
8	177	36,984
9	199	38,180
10	221	39,652
11	243	39,836
12	265	37,628

Source: Adapted from Lombard (1950).

are required, they should be considered an integral part of the orchard and be given the care and attention necessary to minimize their competitive effects.

Planting and care of windbreaks.—If possible, windbreaks should be planted two to three years before citrus is planted. They will then attain sufficient height to afford some protection to orchard trees as they develop (see fig. 2–3). The choice of a tree for windbreaks will depend upon the area and its adaptability to the climate and soil conditions found. Generally, the most desirable tree is one which is rapid-growing, narrow and tall, mechanically strong, of a density sufficient to provide wind protection, and not subject to insects and diseases attacking citrus.

In planting most windbreaks, choose vigorous seedlings, 10 to 12 inches tall with normal and uncramped root systems. These are planted 5 to 6 feet apart in rows, or 10 to 12 feet apart if a filler tree is to be used. The direction of the rows is at right angles to the prevailing wind. A second row, 6 to 8 feet away and offset, is often advantageous in providing a more dense planting at the windward edge of the orchard in very windy areas (fig. 2–4). Some windbreak trees, such as the desert athel or tamarisk, *Tamarix aphylla* (L.) Karst., are started as hardwood cuttings, about ⅝ inch in diameter. These will strike roots easily and are placed three to four feet apart in their permanent positions in the windbreak row.

In areas where wind may be a deterrent factor in the growth of seedling windbreak trees, a shingle or other protection for the windward side may be necessary. This affords protection from the wind and enables the seedling to make a good start.

Early spring planting is desirable to provide as long a growing season the first year as possible. The windbreak tree should be supplied with adequate water and fertilizer to ensure maximum growth. Pehrson (1964) reported blue gum windbreaks in Orange County, California, were 10 to 12 feet tall by the second year, nearly 45 feet tall by the fourth year, and over 75 feet tall by the eighth year where good cultural practices, especially irrigation, were followed. Adequate room for orchard as well as windbreak cultural operations must be provided.

A windbreak will provide lateral protection at orchard tree height level for approximately four to six times its height. Table 2–1 illustrates the reduction of wind velocity 310 feet away from a 70- to 90-foot tall windbreak. In California, windbreaks are normally spaced 330 feet apart, partly because this coincides with the effective protection afforded by mature blue gum trees and partly because it coincides with normal property line divisions. Rows of windbreak trees with lower mature height must be placed closer together to afford similar protection. There is a cumulative effect of windbreaks, so that wind reduction in areas where there are many wind-

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Fig. 2–3. Young blue gum windbreak in Ventura County, California, planted two years before citrus was planted.

Fig. 2–4. An established and well-maintained double row blue gum windbreak in Orange County, California. Pruning has eliminated shading from overhanging branches.

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Fig. 2–5. Blue gum windbreak in Ventura County, California, being pruned by specialized equipment. Note large circular saw mounted on the end of the boom which is swung up and down to cut overhanging branches.

breaks is greater than that provided by a single or a few windbreaks alone.

In developing the windbreak, some pruning or light topping may be desirable to ensure denser growth near the ground. Light cuts, removing only a few inches of the terminal leader, are all that is usually necessary.

On mature trees, pruning of tops at intervals prevents overhanging branches from shading citrus trees and maintains a denser tree. Light pruning at frequent intervals is desirable so that large cuts are avoided. At times, topping is necessary to contain height and force denser growth on the tree. Figure 2–5 illustrates the special pruning equipment which has been developed for this purpose.

Root competition with citrus can be minimized by regular root pruning of windbreak trees. This should be done to a depth of 3 to 5 feet and not closer than 12 feet from the windbreak. Both sides are not cut in the same year, but cutting is alternated from side to side every other year or every two years. Deep subsoiling tools or specialized root pruning equipment are used for this purpose.

Trees for windbreaks.—While trees of several genera are used as windbreaks for citrus in various parts of the world, probably none has more widespread use than *Eucalyptus.*

By far the most widely used tree in California is the blue gum, *Eucalyptus globulus* Labill. This species grows rapidly, is structurally strong, and attains heights of 60 to 100 feet. It maintains a good mantle of foliage, sprouts easily after pruning, is deep rooted, is not easily damaged by root pruning, and is resistant to diseases and most insect pests. The blue gum has successfully withstood temperatures as low as 17° F without undue damage. Its principal disadvantage is its widespread and competitive root system and deciduous bark which causes excessive orchard litter.

E. globulus var. *compacta* is a densely branched dwarfed form of blue gum. This variety is often used as a filler tree between blue gum trees to form a dense break near the ground.

The red gum, *E. rostrata* Schlecht., and the desert gum, *E. rudis* Endl., have been more successful in withstanding high temperatures of the hot desert valleys. Competition with orchard trees, however, has been severe in some areas.

The manna gum, *E. viminalis* Labill., has proven satisfactory in areas too cold for blue gum. It stands extremes of hot and cold and does well near the coast as well as in the hot interior sections. It is a broader tree in relation to its height than blue gum.

For desert valley areas of California, the tamarisk or desert athel, *Tamarix aphylla* (formerly *T. articulata*) is used. It is also recommended for windbreak planting in the Rio Grande Valley of Texas (Young *et al.*, 1963), in the sandy coastal areas of Israel (Uzziel, 1953) and in the Murray River district of Australia (Botham, 1963). The tamarisk is resistant to alkaline or saline conditions and is a dense rapid grower, reaching a height of 30 to 45 feet. Its principal disadvantage is a wide-spreading and very competitive root system, which must be root pruned to prevent undue competition.

Forbes cypress, *Cupressus forbesii* Jepson, and to a limited extent Arizona cypress, *C. arizonica* Greene, are used in coastal areas of California either alone or as a filler in blue gum windbreaks. A compact, tall, and densely foliated tree, cypress provides good wind protection, although its use in California is not as extensive as it once was. Formerly, the Monterey cypress, *C. macrocarpa*

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Hart W., was used to a considerable extent, but its susceptibility to cypress canker, *Coryneum cardinale*, a fungus disease, and to cypress bark beetles caused the loss of many trees, and its use has been discontinued. In Israel, the Italian cypress, *C. sempervirens*, is extensively used and does not compete severely with orchard trees.

Several other trees and shrubs are used for windbreaks to a lesser extent. The Lombardy poplar, *Populus nigra* L. var. *italica* Du Roi, is being tried in California. The oleander, *Nerium oleander* L., has been used in desert areas for wind protection and to stop blowing sand. In Texas, fan palms, *Washingtonia robusta* H. Wendl., close planted in double rows, are suggested for windbreaks (Young *et al.*, 1963). In Florida, Australian pine (*Casurina* spp.) are used extensively in some coastal areas. In Japan, Hodgson (1962) reported the extensive use of narrow hedges of a tall-growing species of *Podocarpus* as secondary windbreaks, which are apparently less competitive than other windbreak material.

Artificial windbreaks.—Wooden or lattice windbreaks for orchard protection have been tried occasionally. They afford quick protection, but cannot be efficiently constructed tall enough to provide much lateral protection. In addition, the initial cost of construction is high (Wahlberg, 1941).

For quick protection, and while a planted windbreak is attaining effective height, temporary individual shelters placed on the windward side of each young tree will provide protection from wind. Such shelters may be of lath, burlap, plastic screen, or other suitable material.

Relative Humidity.—Relative humidity is not a major consideration in selecting a site for citrus. Successful citrus production is found in areas having both low and high humidity. Water transpiration and therefore irrigation needs are greater in areas of low humidity, so adequate quantities of water must be available. Different pests and diseases flourish under low and high humidity conditions and these should be understood. While high humidity is advantageous for tree growth, it has the disadvantage of inducing fungus diseases, and, in combination with abnormally-high temperature, may cause poor fruit texture (Ziegler and Wolfe, 1961).

Low relative humidity, particularly when accompanied by wind, retards or stops fruit and trunk growth. In areas where humidity fluctuates widely, low humidity with wind appears to be most detrimental.

Fig. 2–6. One type of individual wooden shelter for wind protection of trees up to two or three years of age.

Fig. 2–7. Individual burlap wind protectors placed on the windward side of each tree in a coastal area of San Luis Obispo County, California, exposed to chilling winds from the ocean.

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Rainfall.—Information on the amount and seasonal distribution of rainfall is important in planning irrigation and drainage requirements of an orchard. In a few areas of the world rainfall amounts are sufficient and distribution throughout the year so uniform as to make irrigation unnecessary. In many areas, however, while the amount of rainfall may be high, it occurs during a relatively short period, making it necessary to provide for irrigation during the dry months.

Large amounts of rainfall in relatively short periods can also cause erosion and flooding. In areas where this occurs, provisions for adequate control of the excess water should be made.

Soils

Citrus trees grow well on a wide range of soils varying in texture from sands to those high in clay. It is generally agreed, however, that the best soil for citrus is a medium-textured soil of recent alluvial origin, uniform, reasonably deep and fertile, having good internal drainage, and free from injurious salts. On such a soil, a grower has considerable latitude in his cultural operations with little consequence to tree health and production. If soils are more shallow, less uniform, stratified, variable in texture, or have high water tables or toxic salts, allowance for error diminishes rapidly and special practices must be employed to ensure a successful orchard. Knowledge of the soil, then, is very important in selecting a site (Platt, 1965).

The physical and chemical characteristics of soil are discussed fully in Chapter 4. These characteristics should be studied to learn the limits within which successful citrus culture is possible.

Topography.—The topography of land under consideration is not only important from the standpoint of air drainage and frost protection (see p. 50), but also from the standpoint of orchard layout, type of irrigation system, and erosion and flood control.

The increased use of low-volume sprinklers in California during recent years has made it feasible to successfully irrigate trees planted in a regular pattern on steeper slopes than was formerly possible. The steeper the slope, however, the greater the soil erosion hazard. This erosion is not necessarily from irrigation but from rainfall. Such erosion can rapidly move soil from hillsides and deposit it around trees at lower elevations. Special practices in the form of sod strips (Rosedale, 1967), mulches, or intercepting drain ditches must be considered. A hillside planting maintained with sod strips is shown in figure 2–8. On even steeper slopes, contour planting or terraces may be the only practical solution.

Topography from the standpoint of harvesting must also be considered. If special equipment is needed to haul fruit from steep slopes, or if harvesting equipment cannot be operated on steep slopes, costs will be increased.

Soil Uniformity.—Both the surface and subsoil should be investigated for uniformity of type and depth when considering the orchard site. Soils which are not reasonably uniform over the area of an orchard complicate cultural operations, particularly drainage and irrigation. Sandy areas or areas of impaired drainage within an otherwise uniform soil block often require different management practices for optimum tree growth. If these areas can be delineated before the orchard is planted, provisions for differential treatment can be made. After the orchard is planted, it is difficult and often impossible to modify the overall management practices for small areas that differ markedly in some respect of soil characteristic.

If soil conditions of a site under consideration are not known, there are several sources where this information may be obtained. Soil maps prepared by governmental agencies give general and sometimes specific information. Many agricultural laboratories will survey a site and report on soil conditions. Aerial photographs are often informative in revealing old washes or water courses not readily apparent from the ground. The systematic use of a soil tube or auger to examine the soil profile to a depth of 4 to 5 feet provides much information on texture and uniformity.

Water

In the arid and semiarid citrus areas of the world, water for irrigation can be termed the lifeblood of production. Without water in sufficient quantity and acceptable quality there would be no citrus production in these areas. Conversely, in the more humid citrus-growing regions, excess water can be detrimental and means of controlling it must be provided. Water, therefore, whether in limited supply or in excess, must be considered in the selection of an orchard site.

Quantity of Water for Irrigation.—The quantity of water required for citrus production varies greatly and is influenced by the temperature, wind, and humidity of the district; the amount and seasonal distribution of rainfall; the size, age, and planted density of trees; the type

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Fig. 2–8. Sod strips maintained down row middles to prevent erosion on hillside planting in San Diego County, California. Area along tree rows is kept free of weeds by herbicides. Irrigation is by low-head permanent sprinklers.

of soil; and requirements for leaching accumulated salts in some areas. Within relatively short distances, water requirements may differ considerably. In California, for example, the annual irrigation requirement in the coastal zone is 12 to 18 acre inches. Twenty-five miles inland the requirement is 30 to 40 acre inches, and in desert valley areas as much as 8 to 9 acre feet per year are used.

In planning the orchard, provisions for an adequate water supply and an irrigation system capable of applying sufficient water during the time of peak water demand are prerequisites to planting. The supply, in particular, must be adequate for the needs of the trees when they are fully grown.

Quality of Water for Irrigation.—Water quality is an important factor in successful citrus production where irrigation is used. Citrus is classed as a salt-sensitive crop, and the application of water containing an appreciable quantity of salts can seriously limit growth and production. (See vol. II, chap. 3, pp. 243–69.) The limiting concentration of total salts in irrigation water is difficult to establish since several factors are involved. These include the balance between the quantity of salts applied and the quantity lost by leaching as influenced by permeability of the soil; the rate of water use by the plant as influenced by climate; the specific salts or ions present in the water; and the susceptibility of the variety and rootstock grown. Higher salt waters can generally be tolerated if irrigations are frequent, thus preventing a buildup of damaging salt concentrations in the root zone (Bernstein, 1965).

Specific ions in a relatively low total salt water may determine the suitability of the water. Citrus is very sensitive to excess boron and lithium, for example, and waters containing in excess of 0.5 ppm of boron or 0.1 ppm of lithium are considered hazardous (Bernstein, 1965). In the Rio Grande Valley of Texas, irrigation water sometimes contains up to 1.0 ppm of boron, but if water containing 0.3 to 1.0 ppm of boron is used occasional leaching with water containing less than 0.3 ppm of boron is recommended (Bailey *et al.*, 1963). Concentrations of chloride greater than 150 to 200 ppm are generally regarded as excessive, although in some areas higher concentrations have been successfully tolerated with adequate leaching on well-drained soils. Lower values may be dangerous if the soil is poorly drained. The sodium content of water for citrus irrigation should have an SAR (sodium absorption ratio) value of 8 or less and values of 12 to 15 are considered marginal (Wilcox, 1958). Excess quantities of sodium tend to defloculate the soil, decreasing its permeability and making effective irrigation more difficult. Irrigation waters that contain as little as 3 milliequivalents per liter of sodium or chloride (equivalent to about 70 ppm of sodium or 100 ppm of chloride in the water) may

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be injurious if applied as leaf-wetting sprays through a sprinkler system (Bernstein, 1965).

Differences are found between varieties and rootstocks in their susceptibility to salts and specific ions. Lemon, for example, is more susceptible to total salts and boron than orange or grapefruit. Among commercial rootstocks, tolerance to chloride injury is least with sweet orange and citrange, intermediate with sour orange, rough lemon, and tangelo, while Rangpur lime and Cleopatra mandarin are most tolerant (Bernstein, 1965).

If there is any question about the chemical content of the water available for the planned orchard, a chemical analysis should be obtained to determine if toxic salts or ions are present in injurious amounts. In some instances, water may be available from more than one source. If one source is good quality water and one poor, mixing the water from the two sources will often provide an adequate quantity of acceptable quality water for irrigation.

Other Factors To Consider

In addition to the basic factors relating to climate, soil, and water, consideration must be given to still other factors which may have a bearing on the success or failure of the planting.

Varieties.—The variety of citrus selected for planting must be compatible with the environment of the orchard location. Unless there are commercial advantages in growing a variety at a site not entirely suited for its best production or quality, results are likely to prove disappointing. One advantage, for example, might be that a certain variety would mature at a period of the year when supplies from other areas were low, thus offering a marketing advantage.

The variety chosen should have a reasonable chance for successful marketing opportunities. The grower should decide before planting whether his fruit will be used primarily for local consumption or export and whether it is for the fresh fruit or product markets. The principal use of the variety should be established so that the best variety for that use can be chosen. In addition, Savage (1962) suggests that personal likes and dislikes of a grower toward a variety should be considered as well as the congeniality of a rootstock choice. (See Hodgson on horticultural varieties, vol. I. chap. 4.)

Rootstocks.—The rootstock employed must be compatible with soil and water conditions as well as the scion variety selected. The rootstock should also be tolerant to soil-borne fungi and virus diseases present in an area. Sometimes a vector-transmitted virus disease may rule out rootstocks which would be superior from the standpoint of fungus tolerance or salinity. Probably the best example is sour orange (*C. aurantium* L.), a rootstock with good tolerance to gummosis (*Phytophthora* sp.) that is unsuitable for oranges in areas where tristeza virus is present. The choice of rootstocks, therefore, depends upon a number of factors, each of which must be weighed against others.

Fruit-Handling Facilities.—It is desirable that established facilities for packing and shipping or processing fruit be reasonably near the orchard site. The volume of fruit necessary to justify the expenditure for packing or processing plants and equipment is large and the operation requires special knowledge and skill. Only growers or groups of growers with very large plantings find it feasible to operate their own fruit-handling facilities. Most growers ship their fruit through existing facilities of grower cooperatives or contract buyers.

Labor Supply.—An adequate supply of labor should be available. While labor requirements under today's system of culture are relatively low, some operations, such as harvesting, require large and experienced crews. In the United States, most growers utilize the harvesting crews maintained by and under the direction of grower cooperatives or contract labor managers.

An increasing number of owners of citrus property utilize the services of experienced orchard-management organizations. These organizations supervise all orchard operations and provide labor for carrying them out.

Size of Orchard.—Consideration should be given to the size of the orchard to ascertain if it is large enough to justify the capital expenditures required to purchase the specialized equipment needed. Large expenditures, for example, are required for the equipment needed for pest control. In addition, it takes experienced crews to operate this equipment. Most growers, even those with fairly large acreage, have their pest control performed by the equipment and crews maintained by grower cooperatives or contract operators.

Costs.—The profit a citrus enterprise earns is obviously influenced by the total expenditure necessary for land, preparation of the land for planting, irrigation, and drainage systems, equipment, trees, planting, and for bringing the orchard to a self-sustaining age. Also involved are

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the cash overhead costs of taxes and management as well as the investment overhead costs for depreciation on trees and equipment and interest on investment. Many of these costs vary greatly depending upon local conditions and should be carefully considered.

Within any area, as well as between areas, the production of citrus in today's economy is a competitive enterprise. The cumulative net advantage of a particular site must be weighed against that of other locations. The competitive advantage necessary for success may be lost if the total expenditures for development, costs of production, anticipated yields, and fruit quality of the site chosen do not afford or cannot be modified economically to afford at least as great if not greater advantage than other sites.

Rock (1969) stresses the importance of the "Citrus Profit Formula," which is made up of the factors necessary in calculating or estimating citrus growing in any location as an income-producing enterprise. The formula, net returns equal gross returns minus cost, includes four profit factors: yield, packout (reflecting fruit quality and size), price, and cost. Each of these, with the possible exception of price, is influenced by the factors to be considered in selecting the site.

Types of Planting and Land Preparation

Once the site has been determined as suitable from the standpoint of factors already considered, a decision on the type of planting and orchard layout must be made. This will also involve the kind and amount of land preparation that is necessary.

In preparing land for planting, the primary consideration in arid areas is to establish grades on which water for irrigation can be uniformly and efficiently applied without soil erosion. In areas of high rainfall, consideration must be given to removal of excess water from the orchard. Often, both factors are involved—the need for irrigation during one season of the year and the requirement for adequate drainage during another.

Three general types of planting are used and the one most suitable for a particular site is dictated primarily by the natural topography and soil type. In some large orchards, more than one type of planting may be required.

Standard Planting.—Most citrus throughout the world is planted on land which is level or has only a slight slope. On such land, trees are set in what is termed a "standard planting," i.e., set a uniform distance apart in a regular pattern of straight rows running in each direction (see Planting Systems, p. 65).

All types of irrigation are used on standard planted orchards, but the particular system will depend upon the degree of slope and soil type. Furrow irrigation is generally used on slopes with grades of between 0.1 and 3.0 per cent at the extremes, although grades in excess of 2.0 per cent

Fig. 2–9. A California orchard planted by the rectangular system (22 × 11 feet) on rolling topography. Irrigation is by drag-line, low volume, low-head sprinklers.

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may cause problems (Brown, 1962; Burger, 1967). On most medium-textured soils, a grade of 0.5 to 1.5 per cent is preferable (Burger, 1967), but 2.0 per cent may be satisfactory in some cases (Johnston, 1953). Sandy soils, which are more subject to erosion, tolerate less slope than clay soils.

Irrigation by basins or borders is generally used on very porous soils which have been brought to zero-grade (level) or, at the most, a 0.1 to 0.2 grade. Large volumes of water to quickly cover the area and provide uniform application are used.

Sprinkler irrigation, particularly with low-volume sprinklers, is used successfully in standard planted orchards on slopes ranging from zero grade up to grades greater than is possible by surface methods (see fig. 2–9). If sprinklers are used, the degree of slope which can be tolerated depends largely on the soil erosion hazard from heavy rainfall.

In preparing virgin land for standard planting, the usual practice in most areas is to first clear land of native vegetation and remove large rocks and other debris. Often deep plowing is needed to bring up roots, which are then piled up and burned or removed. Possible infection of young trees by Armillaria fungus, *Armillaria mellea,* (Botham, 1963), or mushroom root rot, *Clitocybe tabescens* (Scop. ex Fr.) Bres. (Lawrence, 1962), is reduced by thorough removal of the roots of native trees. Where compaction layers or plow soles are present, subsoiling will break up these layers. In some areas of California, hardpan soils have been successfully broken up and improved by deep chiseling to a depth of 4 feet or more. On some of the poorly drained soils of southern Florida, it is desirable to plow to 42 inches to break up hardpan and thoroughly mix it with the soil. Dolomite or lime, if needed, is added at the same time (Lawrence, 1962).

Land needing little or no leveling is harrowed or disced and then dragged to eliminate high spots and fill depressions. Where grading or leveling must be done to assure uniform irrigation and drainage, the services of an experienced operator is a wise investment.

In leveling land to bring it to the desired grade, the importance of moving as little topsoil as possible must be kept in mind. Few soils are of uniform enough fertility throughout the upper and lower horizons to permit removal of topsoil without reducing tree growth. Where heavy cuts must be made to eliminate high spots, it is desirable to stockpile the topsoil, undercut the high spots, and then replace the topsoil on the cut areas. Myers, Ross, and Carter (1963) suggested bench leveling for land on which the topography does not permit a whole field to be leveled without excessive topsoil removal. They further stated that less soil is removed if benched areas follow the contour of the land.

While it is not always essential, it is highly desirable that irrigation and drainage systems be installed before trees are planted. In preparing land, an irrigation before the trees are planted will indicate any faults in the leveling or grade, and these may be corrected.

If a plowsole has developed on land farmed to other crops, it can be broken up and the soil improved by planting a deep-rooted green manure crop and plowing it under before new trees are planted. Purple vetch (*Vicia atropurpurea* Desf.), annual yellow sweet clover (*Melilotus indica* All.), mustards (*Brassica* sp.), Colorado River hemp (*Sesbania macrocarpa* Mukl.), and mallow (*Malva* sp.) are used for this purpose in different areas of California. In Florida, hairy indigo and crotalaria (*Crotalaria striata*) are used (Lawrence, 1961).

Land formerly planted to citrus may be infested with the citrus nematode, *Tylenchulus semipenetrans,* as well as *Phytophthora* spp. of soil fungi. Olives, grapes, and persimmons are also hosts to the citrus nematode. In California where these pests are present, a preplant treatment of the soil with a suitable fumigant will assure better growth of the young trees (Baines *et al.,* 1966; Klotz *et al.,* 1960).

Contour Planting.—Contour planting is used when the natural topography of the land is too steep to permit uniform surface irrigation down the slope without excessive erosion. Generally, contour planting is used on slopes in excess of 3 per cent but not greater than 25 to 30 per cent.

As the name implies, in contour planting the trees are set in rows following a uniform grade along the natural contour of the land (fig. 2–10). Land of very slight slope can be leveled to form contour benches for basin or border irrigation (fig. 2–11). On steeper slopes, furrows or sprinklers are generally used. Brown (1963), in discussing contour planting, emphasizes that soil depth must be adequate and that soils of medium texture are preferable.

While contour planting permits use of lands too steep for standard planting, there are certain disadvantages, particularly when it is used on steeper slopes. These include fewer trees per acre; short rows, called stub rows, spike rows, and

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Fig. 2–10. Contour-grade planting on rolling topography in southern California. Irrigation is by furrows or sprinklers.

Fig. 2–11. Lemon orchard in Ventura County, California, planted with contour rows to provide uniform grade for furrow irrigation. These trees have been hedged and topped mechanically to control growth.

filler rows (Brown, 1963), which are often necessary to utilize as much land as possible while maintaining the grade; danger of water breaking out down the slope; and frequently increased costs of weed and pest control, harvesting, and orchard protection.

Planting on Terraces.—On lands with slopes in excess of 25 to 30 per cent, it is generally advisable to build preformed terraces. Like contour plantings, these follow a predetermined contour grade along the slope of a hill, but are built up to form benches on which trees are planted.

Citrus is grown on terraces in many countries where adequate level land is at a premium. Most citrus in Japan, for example, is grown on terraces built with stones and filled with soil (Bitters, 1964). In the Mediterranean area, terraces are used in certain districts of Italy (Burke, 1962) and Spain (Gonzalez-Sicilia, 1968). These terraces, supported by walls of rock, are usually expensive to construct, but do provide land on which to grow citrus if other land is not available.

In California, there is a limited use of preformed terraces which are constructed by cutting benches 15 to 20 feet wide along the contour grade (fig. 2–12). The bench is sloped slightly toward the hill to prevent water from breaking out and washing straight down the hill. Trees are planted on the outer edge of the terrace. Erosion is often a problem on terraces, but control is possible by the use of cover crops. In high rainfall areas of Japan, erosion is controlled by cover crops of love grass and fescue grass (Bitters, 1964).

With both contours and terraces, the services and advice of a competent engineer are valuable in assuring that they are planned and laid out correctly.

Planting on Beds or Ridges.—Planting on beds or ridges is frequently practiced in the Far East and in southern Florida, where poorly drained soils cause high water tables. In the Far East, where rainfall is heavy and water tables are high, citrus trees are planted on ridges, banks, or

Fig. 2–12. Preformed terraces formed on a steep hillside in Ventura County, California. Irrigation is by furrows on a uniform contour slope. Concrete pipe risers in foreground used to collect and carry away excess water to prevent erosion.

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Fig. 12–13. Two-row beds for citrus in southern Florida west of the Indian River area. Ditches for drainage are spaced between beds. Tree rows are kept weed-free and a covercrop is planted between rows.

mounds formed by digging out ditches to provide drainage for very flat land (Chen and Dragavcev, 1958).

On the poorly drained "flatwoods" soils of southern Florida, two- to four-row beds are constructed (fig. 2–13). Ditches between beds remove excess water, and, in some cases, provide irrigation. High single row beds are less desirable since they permit root damage by cultivation, exposure, and lack of moisture (Anonymous, 1961). The beds must be level to prevent erosion. After beds are constructed and leveled, lime is added, if needed, and a quick growing cover crop such as rye or oats is planted to help stabilize the soil (Lawrence, 1962).

Fig. 2–14. Soil erosion as a result of uncontrolled flood water from heavy rains.

Surface and Subsurface Drainage.—In many areas, preparing land for adequate drainage of surface and subsurface water is as important as proper preparation for irrigation. Drainage systems should be installed, if necessary, before the orchard is planted.

Surface drainage.—This is required to carry away excess water from irrigation or rainfall, thus preventing erosion and flooding. Ditches or conduits to collect water and direct it to natural drainage channels are used in many orchards. Often, intercepting ditches above an orchard are necessary to divert flood water and prevent it from flowing through the orchard. Examples of flooding problems resulting from inadequate surface drainage are shown in figs. 2–14 and 2–15.

In central California, return flow systems (Houston and Schade, 1966; Schade, 1967), have not only alleviated flooding at the ends of irrigation runs but have contributed to more effective irrigation. Lawrence (1962) stresses the importance of adequate surface drainage in the poorly-drained soils of southern Florida. There a system of ditches and pumps is used to remove excess water.

Subsurface drainage.—This must be provided in areas in which internal soil drainage is

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impaired to the point where high water tables and salinity may cause poor tree growth and production. According to Houston (1967), poorly drained land causes most salinity problems; poor root environment from high water tables, particularly with those that fluctuate; more difficult farming operations; an increase in soil compaction; and greater incidence of root diseases.

Tile drains, installed at a depth to control the height of the water table and provide an outlet for the leaching and removal of high salinity water, are most commonly used. The depth of tile lines will depend somewhat on the depth of the impervious layer of soil. In Florida, tile lines are not less than 3 feet from the soil surface (Lawrence, 1962). In California, they are usually placed no shallower than 5 feet. In some areas, open ditches may be constructed deep enough to provide adequate subsurface drainage.

The installation of subsurface drainage is generally expensive and often involves many owners in an area. For this reason, drainage districts are often formed to connect the individual systems together and provide community collection and disposal facilities for drainage effluent from individual properties.

In some cases, it is advantageous to install an intercepting tile line above an orchard site to collect and divert subsurface water from higher elevations. Such intercepting lines help prevent water from entering the orchard area.

Once installed, tile lines must be maintained in good working condition. Clogged lines or improperly installed lines can be a source of considerable difficulty. In California, clogged lines have resulted from improper packing. In Florida, Ford and Spencer (1962) reported clogging as a result of bacterial reduction of ferrous iron, which enters tile lines in areas of acid fine sandy soils. Competent engineering advice should be sought before drainage tiles are installed.

Planting Systems

A number of different planting systems—the pattern in which trees are set out in the orchard—have been used. These include the rectangular (square), triangular, hexagonal, and quincunx systems. Systems other than rectangular and quincunx result in diagonal rows, which are often confusing and sometimes more difficult to manage from a cultural standpoint. Consequently, they are now seldom used.

In recent years, most citrus orchards, other than those on contours or terraces, have been planted by the rectangular system in which trees are set at the intersections of lines perpendicular to each other. Usually these lines are parallel to property lines or straight field boundaries. Depending upon certain factors discussed in the next section, the number of trees per acre can be varied

Fig. 2–15. Trunks of young trees which have been covered by soil deposited from uncontrolled floodwater.

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by increasing or decreasing the distance between trees in the rows. The distance between rows is less flexible since sufficient room for orchard equipment must be provided.

To a limited extent, the quincunx system of planting is employed by some growers. In this system, a temporary tree is planted in the middle of a square, which gives 78 per cent more trees per acre than a square planting and provides for additional production during the early life of the orchard. The principal disadvantage of a quincunx planting, other than some inconvenience in orchard operations, is the natural reluctance of the owner to remove temporary trees in time to prevent excessive crowding of permanent trees.

Planting Distances

Planting distances for citrus have been the subject of considerable study, and, in practice, considerable change in the last two decades. Investigation has centered on the distance which would provide optimum yields during the entire life of the orchard, yet allow sufficient space to carry on necessary cultural operations.

For many years, and to some extent today, trees have been planted at distances which assure adequate room for the tree when it reaches maturity. The distance between trees has varied with variety, rootstock, type of soil, and climate, and has generally ranged from 20 to 35 feet in each direction, resulting in tree densities of 109 to 35 trees per acre. For many years in California, the most commonly used spacing for navel oranges were 20 by 20 or 22 by 22 feet; for Valencias, 22 by 22 to 28 by 28 feet; for lemons, 22 by 22 to 30 by 30 feet; and for grapefruit, 24 by 24 to 30 by 30 feet. Similar distances were used in South Africa (Burger, 1967). Planting distances in Florida were 25 by 25 feet for oranges, tangerines, and tangelos; and 30 by 30 to 35 by 35 feet for grapefruit (Lawrence, 1962). Orchards with trees planted at these distances result in low production per acre when trees are young, but afford maximum production from about 15 years to full maturity.

Fig. 2–16. An old crowded seedling orange orchard showing the shading out of branches and complete loss of tree skirts. Fruit is produced only in the upper portion of the tree where there is sufficient light.

Since the mid-1940's, increased costs of land, development, and cultural practices have caused growers in many areas of the world to seek maximum early production to compensate for higher costs. Consequently, the trend has been to reduce distances between trees and provide for a greater number of trees, or producing units, per acre.

Close planting is not new in citrus, having been practiced in some areas for many years. The older orchards of Italy (Burke, 1962) and of Spain (Camp, 1957) have high tree densities ranging up to 400 and, in some cases, 600 trees per acre. Yields in these close plantings as the trees become older, however, are maintained only by a great amount of selective pruning and hand work. Trees in older orchards of Algeria (Burke, 1952) and Israel (Patt, 1953) were planted at distances of from 10 to 13 feet, but had complete shading out of lower branches and low production because of excessive crowding.

McCarty (1966), in a study of high-density deciduous orchards in Europe, found that even though yields per acre were high, the costs of training and controlling growth were expensive and sometimes uneconomical. He suggested that high-density citrus plantings might be feasible if dwarfing rootstocks could be found to reduce the amount of training and pruning necessary.

When trees are planted in high densities, illumination becomes a limiting factor in both maintenance of foliage and in yields. Monselise (1951) reported that while citrus leaves can survive at light intensities of less than one per cent of full sunlight, other leaves on the tree receiving full illumination probably contribute to their survival. He further commented that full sunlight or illumination is required for maximum yields. The effects on tree growth and yield by orchard thinning through tree removal in close planted orchards have been shown by Patt (1953). He used

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orchards of 17-year-old Shamouti sweet orange on Palestine sweet lime, planted 13 by 13 feet (258 trees per acre). The lower branches to a height of about four feet were shaded out with little or no foliage, and yields were low. Every other row in one treatment (thinning ½), and every third row in another (thinning ⅓), either diagonally or in the direction of cultivation, was removed. Patt found significant increases in yield, as well as tree size and trunk circumference, two years after thinning. Monselise (1951), using these trees, found illumination values of 51.2 per cent (of total sunlight) in the one-half thinned and 16.8 to 25.3 per cent in the one-third thinned blocks as compared to 0.72 per cent in unthinned blocks.

To attain greater early production and yet not crowd trees to such an extent as to cause excessive shading, hedgerow or double planting is now widely used (fig. 2–17). In this method of close planting, rows are far enough apart to allow room for cultural operations and harvesting and to provide adequate illumination. Trees in the row are spaced close together, usually one half the distance of that between rows. Row direction is preferably north and south to take maximum advantage of sunlight. In areas subject to frosts, however, hedgerows planted perpendicular to normal air drainage may cause lower orchard temperatures by blocking this flow of air. McCarty *el al.* (1968) found hedgerow plantings also blocked the air blast from wind machines so that slightly lower temperatures resulted. In planting hedgerows, therefore, the frost hazard must be considered.

There is ample evidence to show that the double-planted orchards have high yields during the early years. There are, however, several problems still unresolved for all conditions that pertain to the management of hedgerow plantings to assure satisfactory yields over the full life of the orchard.

One of the earliest recorded trials is that reported by Lombard (1950*b*). In a ten-year-old California orchard of old-line Valencia oranges on sour orange rootstock, with trees planted at a distance of 12 feet apart in rows 23 feet apart, every other tree in each row was removed, leaving a 24 by 23 foot spacing in part of the orchard. During the succeeding ten years (10- to 20-year tree-age period), the double-set portion averaged 58 per cent more fruit per acre than the thinned portion, although production per tree on the single set orchard was greater. The per acre yield of the double-set planting in this trial has continued to surpass that of the single-set block by a substantial amount.

The results of this trial would appear to indicate that double-set orchards provide high production over the life of an orchard. It should be noted, however, that the scion-rootstock combination was less vigorous than those widely used

Fig. 2–17. Hedgerow planting of old-line Valencia oranges on sweet orange rootstock in Ventura County, California, illustrating the solid wall of foliage developed in such a planting. These trees are set 9 feet apart in rows 22 feet apart and are approximately 18 years old.

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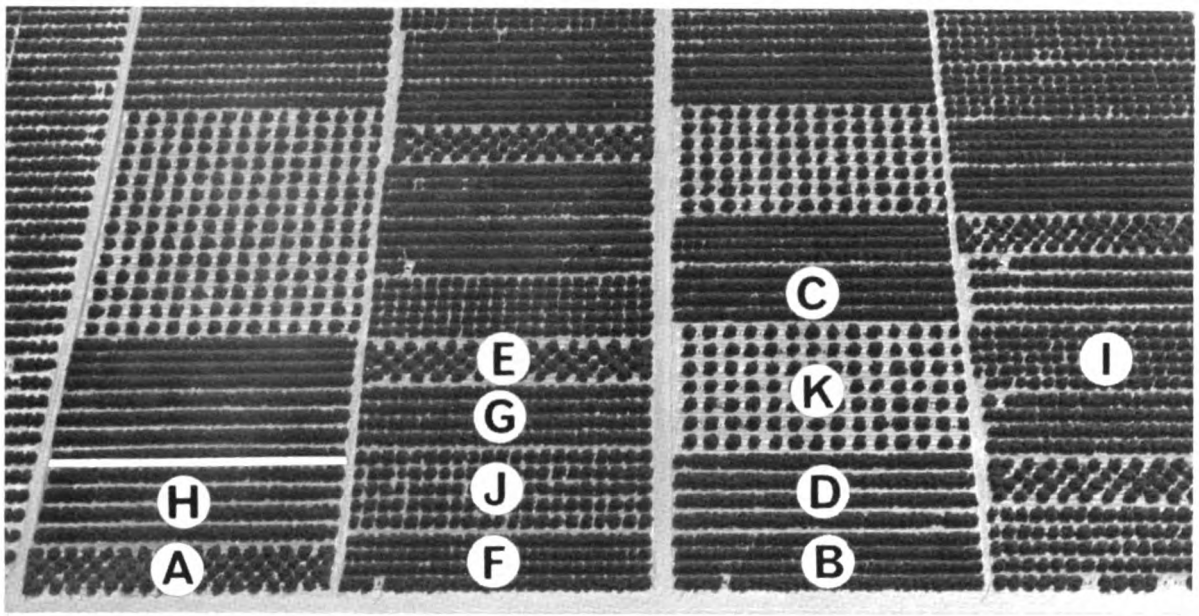

Fig. 2–18. Aerial view of the University of California 40-acre tree spacing trial, Kern County Land Company, Bakersfield. The trees, planted in 1961, were eight years old at the time of the photo. Planting distances, replicated six times, are represented as follows: *A*, 9 × 11 feet (thinned in 1967 to a rectangular planting of 18 × 22 feet with a tree in the center); *B*, 9 × 15 feet; *C*, 9 × 18 feet; *D*, 9 × 22 feet; *E*, 11 × 11 feet (thinned in 1967 to a quincunx planting of 22 × 22 feet with a tree in the center); *F*, 11 × 15 feet; *G*, 11 × 18 feet; *H*, 11 × 22 feet; *I*, 15 × 15 feet; *J*, 15 × 18 feet; and *K*, 22 × 22 feet. (Photo by C. D. McCarty.)

today. If more vigorous scion-rootstock combinations are used or mature tree size is generally larger, other factors must be considered.

Studies by Savage (1959) in Florida, before hedging and topping was practiced, showed that maximum yields during the first twenty-four years came from tree densities of from 90 to 99 trees per acre; between 25 to 40 years from approximately eighty trees per acre; and at over forty years from fewer than 60 trees per acre. Orchards kept at 90 to 100 trees per acre dropped in production sharply after twenty-five years. He suggested that the most practical management is to double-set, then prune back and finally remove alternate trees to prevent crowding and loss of yield as the orchard matures. Hedging, topping, or "buckhorning" and thinning by tree removal are used in Florida to prevent crowding and maintain yields (Norris, 1961, 1962). Currently high yields are maintained in 25- to 50-year-old orchards, set at 96 to 130 trees per acre, when hedging and topping are practiced.

In California, many orchards are planted as hedgerows with trees set at 11 by 22 feet. Some growers expect to maintain the hedgerow plantings over the life of the orchard while others plan to follow a program of tree removal as the trees start to crowd. Tree removal is described, however, as one of the most painful tasks confronting a grower and is often delayed until crowding occurs.

A large tree spacing trial, designed to provide information on the best planting distances and the management involved for maximum per acre production during the life of the orchard, has been established in California (Lewis, McCarty, and Crim, 1962). Trees of a vigorous combination, Frost nucellar Washington navel orange on Troyer citrange rootstock, were planted in 1961 at eleven different spacings ranging from 9 by 11 to 22 by 22 feet.

Results of the first five years of harvest, in boxes per tree and per acre for the different spacings, are shown in table 2–5. Boswell *et al.*, (1970) report that the two closest spacings, 9 by 11 feet and 11 by 11 feet, had to be thinned on the diagonal to one-half the original stand following the third harvest in 1966–67 because of loss of yield due to crowding and shading out of lower branches. The skirts on the remaining trees re-

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Table 2–5
UNIVERSITY OF CALIFORNIA-KERN COUNTY LAND COMPANY SPACING TRIAL
YIELD RECORDS CONVERTED TO BOXES PER ACRE*

Spacing	Trees Per Acre	1964–65 Boxes Per Tree	1964–65 Boxes Per Acre	1965–66 Boxes Per Tree	1965–66 Boxes Per Acre	1966–67 Boxes Per Tree	1966–67 Boxes Per Acre	1967–68† Boxes Per Tree	1967–68† Boxes Per Acre	1968–69 Boxes Per Tree	1968–69 Boxes Per Acre	5-Year Total Yield 1964–69 Boxes Per Tree	5-Year Total Yield 1964–69 Boxes Per Acre
T *R*													
9 × 11	440‡	0.98	431	0.80	352	0.75	330	1.19	262	2.81	618	6.53	1,993
9 × 15‖	324	1.12	362	1.05	340	1.56	505	0.51	165	1.85	599	6.09	1,971
9 × 18#	269	1.37	369	1.19	322	1.80	484	0.86	231	2.34	629	7.56	2,035
9 × 22	220	2.20	263	1.21	266	2.36	519	1.04	229	2.79	614	8.60	1,891
11 × 11	360§	0.99	357	0.89	320	1.40	504	1.52	274	3.62	652	8.42	2,107
11 × 15‖	264	1.05	276	1.51	396	2.19	578	0.79	209	2.32	612	7.86	2,071
11 × 18#	220	1.20	265	1.60	352	2.40	528	1.28	282	2.96	651	9.44	2,078
11 × 22	180	1.14	205	1.47	265	3.10	558	1.67	301	3.76	677	11.14	2,006
15 × 15‖	194	0.92	179	1.58	307	2.83	549	1.04	202	3.12	605	9.49	1,842
15 × 18#	161	1.04	168	1.50	241	3.16	509	1.68	271	4.00	644	11.38	1,833
22 × 22	90	1.38	124	1.49	135	3.89	350	2.62	236	5.34	481	14.72	1,326
Mean		1.13	273	1.29	299	2.31	492	1.29	242	3.17	617	9.20	1,923

Source: Adapted from Boswell *et al.* (1970).

* Trees: Frost nucellar Washington naval on Troyer citrange rootstock, planted 1961;
Trial: Six replications of eleven planting distances; 50 pounds net fruit per box.

† All yields depressed due to adverse weather.

‡ Reduced to 220 trees per acre following 1966–67 harvest.

§ Reduced to 180 trees per acre following 1966–67 harvest.

‖ Heavily hedged following 1966–67 harvest.

Moderately hedged following 1966–67 harvest.

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grew, however, and increased production per acre is reflected in the 1968–69 harvest. Blocks with 15- and 18-foot spacing between rows required hedging to maintain adequate illumination and allow sufficient working space in row middles. All trees were topped to a 13-foot height in 1967 and maintained at this height with subsequent topping. They found that pruning to avoid crowding reduced yield in proportion to the amount of foliage removed.

Planting density was found to be a major factor affecting fruit color and size. Orange color developed first, was more intense and fruit was larger in the 22 by 22 foot spacing than in other spacings. Coloring of fruit from trees in the high density plantings was delayed as much as 45 days after reaching legal maturity although this delay was not apparent until illumination was reduced by crowding and shading. Fruit analyses showed no differences in internal quality when comparisons were made in December, after all fruit had reached legal maturity. Recent analyses (unpublished data), however, show trends toward a higher soluble solids to acid ratio on early season fruit from wide spacing. This could be an important factor to growers wanting fruit for early maturity. Since these differences in fruit quality and size occurred under optimum nitrogen and moisture levels for all spacings, it is concluded that they were the result of illumination as affected by planting density.

In analyzing the costs involved in establishing and maintaining the various spacings, Boswell *et al.* (1970) found a five-year net loss per acre on the 9 by 11 foot and 11 by 11 foot spacing. This was due primarily to higher per acre costs for trees and planting, tree removal when these spacings were thinned, pest control, fertilization, and frost protection. The greater early production from these spacings did not compensate for the added costs. Considering all aspects of cost, the 11 by 22 foot spacing brought the greatest per acre net returns after five years of harvest.

Table 2–6
FLORIDA CITRUS EXPERIMENT STATION
DAVENPORT GROVE SPACING TRIAL

Spacing	Trees Per Acre	Effect of Spacing on Fruit Yield					
		Boxes Per Tree°			Boxes Per Acre°		
		1967	1968	1969	1967	1968	1969
20 × 25 ft.	87	1.65	1.48	2.44	144	128	212
15 × 20	145	1.53	1.40	2.25	222	203	326
10 × 15	290	1.24	0.93	2.13	360	269	619

Source: Adapted from Phillips (1969).
° Estimated at 90 pounds net fruit per box.

Another spacing trial, this one in Florida, compares the production and performance of Pineapple orange on rough lemon rootstock planted in 1960 at spacings of 10 by 15, 15 by 20 and 20 by 25 feet. Phillips (1969) reports significant differences between spacings in yield per acre for the 1967, 1968 and 1969 harvests with the highest yield coming from the closest spacing (table 2–6). He also found maturity was delayed in fruit from the 10 by 15 foot spacing and speculated that the higher acid resulting in a lower soluble solids to acid ratio was caused by lower illumination. Similar to the results of the California spacing trial, he found that the pruning required to control excessive vegetative growth and prevent crowding, reduced yields. Whether high production can be maintained at the close spacing as the trees grow older remains to be determined.

Actual planting distances for maximum yields will vary depending upon the vigor of the scion-rootstock combination, the soil, and the climate. A knowledge of mature tree size for the particular situation will help decide what the spacing should be. Trials and observations indicate that planting distances so close as to require considerable pruning or tree removal before 10 years of age to prevent loss of yield due to insufficient illumination are of questionable economic value. Closer spacing of trees in the row but with enough distance for adequate illumination and working area between the rows will assure greater early production but a positive program of tree control, carried out with conviction, will be necessary to maintain maximum production over the life of the orchard.

PLANTING THE ORCHARD

Orchard Layout

After soil has been prepared and a decision made on the planting system and planting distances, individual tree sites are located and marked. Several methods may be employed in locating tree sites, depending upon the experience, skill, and inclination of the grower.

Regardless of method, the first step is to establish base lines from which all other measurements are made. These base lines, usually established by the use of a surveyor's transit, are normally parallel to the property line. One base line forms the base row. Another, running at right

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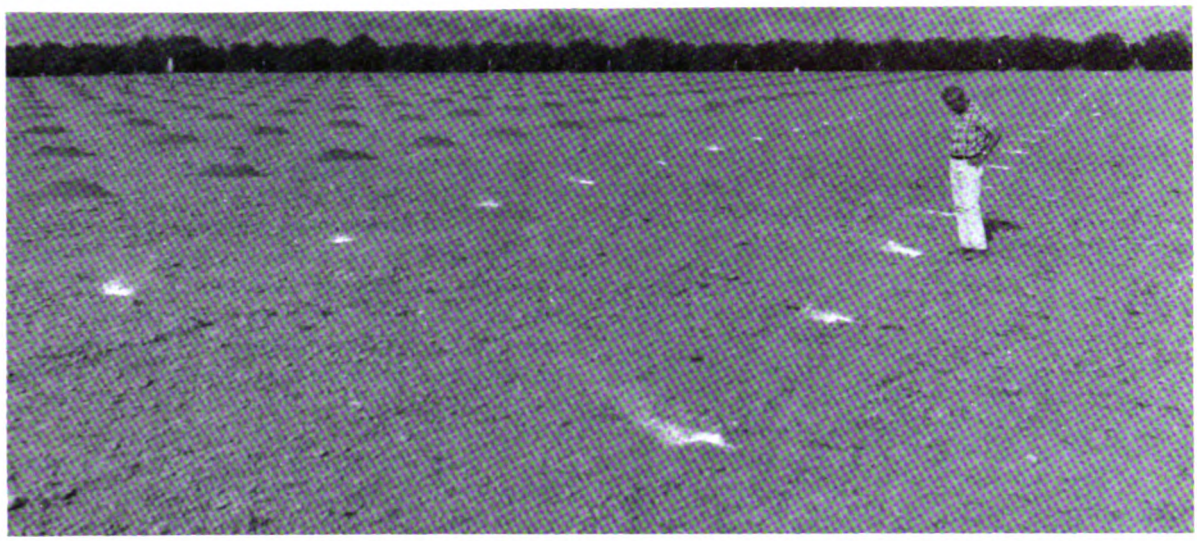

Fig. 2–19. Tree locations established by placing a handful of powdered gypsum at each mark on a wire stretched across the field. In the background, tree holes have been dug by a power auger mounted on a tractor.

angles to the first, forms the line at which the first tree in each row is placed.

Formerly, it was the practice to rather laboriously use a surveyor's transit to locate and mark each tree site. Faster and less expensive methods are used today. By one method, using the base lines as reference points, a wire or chain, marked at the desired intervals of tree spacing, is stretched across the field. A handful of powdered gypsum or other easily visible material is dropped at each mark to indicate the tree site. Tree holes are then dug at these indicated spots (fig. 2–19).

Another method, again using base lines as reference points, is to use a tractor with row markers or a chisel to form a visible grid pattern on the field. Each pass across the field is made at the predetermined spacing distance with the last pass being the reference line for the next. The intersection of the marks indicates tree sites. An experienced tractor driver can thus mark a field for planting in a short time. (fig. 2–20).

It is important that adequate space for turning cultural and harvesting equipment be provided at the end of the rows. This is particularly true if ditches, irrigation outlets, or windbreaks are along the borders of the orchard. Lawrence (1962) reported that it is customary in Florida to leave 15 feet between the last tree and the property line, but he suggested that 20 feet would be preferable.

In many California orchards, it is customary to provide a wider space between every six rows of lemons and every four rows of oranges as "picking drives." This permits fruit-hauling equipment to travel down these drives with less injury to fruit and limbs. In harvesting, fruit is brought to these drives for transport out of the orchard. Looking into the future, equipment providing mechanical harvesting or mechanical aids

Fig. 2–20. Field marked off in two directions for planting by pulling a shank with a tractor. Planting holes are being dug with a power auger.

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to harvesting may eliminate the necessity for these special picking drives.

Selection of Nursery Trees

Perhaps the most important factor in establishing a successful orchard is selection of the best nursery trees available. No combination of favorable climate, good soil and water, and skillful management can overcome the handicap of inferior trees. The trees selected should come from good parentage both as to scion and rootstock, be free from known virus disease, and be true-to-type as to variety. Such trees have the inherent ability to produce large crops for many years, and even though they may be slightly more costly they are well worth the investment.

That the use of superior trees is recognized as important is evidenced by the adoption of certification or registration programs in many parts of the world (Mather, 1964; Reuther *et al.*, 1968*a*, 1968*b*; Lawrence, 1968; Bridges, 1967; Allen and Carpenter, 1966; Olson and Sleeth, 1965; Rossetti, *et al.*, 1965; Beñatena and Pujol, 1965). These programs, while differing slightly from area to area, basically provide for the propagation of virus-free, true-to-type citrus nursery trees.

Well-grown nursery trees are vigorous and have large deep green leaves and straight trunks, with smooth textured and clean bark. The root system should have an ample lateral and feeder root system and a relatively straight taproot. When trees are balled for transplanting, an examination in the nursery before digging will reveal if there is a good feeder root system within the confines of the ball. It will also reveal the presence of possible *Phytophthora* spp. lesions on larger roots, and trees with such lesions should be rejected.

The ideal height of the bud union will vary in different areas of the world depending on the disease hazard, cultural practices, and soil types. In California, for example, a height of 8 to 10 inches is preferred; in Florida, 3 to 4 inches; and in some Mediterranean countries, 18 to 24 inches above the soil level.

The best nursery trees are usually those that are ready to transplant one year after budding. Some slow-growing varieties or rootstock-scion combinations, however, may require two years to reach acceptable size. There is sometimes an element of doubt in two-year-old budlings since they may have been smaller when one-year budlings of the same lot were dug and were left for an extra year to attain sufficient size. This is an indication of an inherently weaker tree, and such budlings should be avoided (Ziegler and Wolfe, 1961). Some growers, on the other hand, prefer two-year-old budlings and contract with a nurseryman to grow them. Such trees are perfectly acceptable if the conditions under which they were grown are known.

The caliper, or diameter of the trunk one inch above the bud union, of well-grown nursery trees will vary somewhat by area, variety, and rootstock. In California, most one-year-old budlings should caliper between ⅜ to ¾ inches, and two-year-old budlings, ¾ to 1¼ inches. In Florida, nursery trees should caliper from ⅝ to 1¼ inches (Lawrence, 1962).

Within the range of acceptable caliper, and as long as zygotic or off-type seedlings are not involved, the size of the budling has little effect on ultimate tree size. Mendel (1940), in Israel, found that appreciable size difference in budlings of Shamouti sweet orange on Palestine sweet lime rootstock became minor four years after they were planted in the orchard. In Florida, Gardner and Horanic (1959) used budlings of Parson Brown and Valencia sweet orange ranging from ½ to ⅞ inches in caliper on several rootstocks. They found no pronounced correlation between initial budling size and ultimate tree size or between initial size and yield within the various rootstocks seventeen years after planting.

It is advisable to inspect trees in the nursery before purchasing to be sure they are of uniform size, vigorous, and of good quality. It is wise to deal with reputable nurserymen who take pride in the production of superior trees.

Time of Planting

The best time of year to plant citrus trees varies with the climate of a locality and the growth condition of the nursery stock. In areas of tropical and semitropical climate, planting can be undertaken at any season of the year with reasonable expectations of success. In areas where winter frosts are prevalent and summer heat severe, planting times become more critical.

Lawrence (1962) pointed out that in Florida the best time to plant is late winter or early spring when trees are most dormant. If trees are planted in early December, they should be banked with soil for cold protection.

Bailey and Maxwell (1963) indicated that late December to January is considered the best planting time in the Rio Grande Valley of Texas, since trees are dormant at that time. They also

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pointed out the need for protection in the event of freezes.

In California and Arizona, most citrus trees are planted between late February and May, after the danger of severe frost has passed and before the onset of high summer temperatures. Trees planted during this period become well established through the long growing season and are better able to withstand the low temperatures of the following winter. Trees planted in summer are subjected to greater shock from high temperatures and often fail to start properly. In mild, frost-protected locations, fall planting of balled trees may be successful.

Trees that are dug for planting while in an active growth flush do not resume growth after planting as well as those dug just before a growth flush.

Planting the Trees

Citrus trees are dug in the nursery for transplanting to the orchard either as balled or bare root trees. Each method has its advantages and disadvantages.

Planting balled trees has generally been found best for the more arid areas and is the prevailing method in California. The adhering ball of soil around the root system protects it and prevents the fibrous feeder roots from drying. Balled trees may usually be held longer after digging and before planting without injury to the root system provided the balls are kept moist. The soil in the ball, however, must be of the same or similar texture to that in the orchard to insure adequate irrigation of the young tree. Differences in soil texture and in some cases, structure, between ball and orchard soil were found by Grover, Calhoon, and Hotchkiss (1964) to have a marked effect on the movement of irrigation water into the ball. Root densities outside the ball, as a measure of tree response to adequate moisture, were determined to be lowest where the contrast in texture between ball soil and orchard soil was greatest, i.e., clay soil versus sandy soil. To assure the tree gets a proper start, careful visual inspection of the ball soil or the use of tensiometers placed in the ball will indicate whether adequate moisture is being maintained.

The use of bare root trees, on the other hand, is common but not exclusive to more humid areas where drying of the roots is not so rapid. This, though, does not mean that careful attention to prevent root drying is not extremely important (Lawrence, 1962; Miller, 1968). Grimm (1957), in a study of the factors affecting the transplanting success of bare root citrus trees in Florida, found that protection of the roots from drying out was the most important single factor for promoting vigorous tree growth. Gagnard and Molin (1956), used polyvinyl bags over the root systems of bare root trees to prevent drying. Trees thus bagged for three days made excellent growth while unbagged trees, held for the same period, died after planting.

Advantages of planting bare root trees are: preservation of more of the root system; an opportunity to detect and eliminate trees with diseased or malformed roots; ability to plant in soils differing markedly in texture from those of the nursery; less weight to handle; and possible elimination of noxious weeds which might infect a nursery.

Regardless of method, it is important that trees be handled expeditiously but with care to ensure a successful start in the orchard. Provisions must be made to plant trees immediately on bringing them to the field from sheltered areas and to water them as soon as they are planted. Teamwork and close supervision of the planting crew are important.

Fig. 2–21. A balled tree set in a hole ready to be filled with soil. The hole was dug by a power auger with a sweep attachment to form a basin.

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Fig. 2–22. Planting crew setting citrus trees in a new orchard. Water is applied in the basin immediately after the tree is planted. The equipment in the background was used in leveling the land prior to planting.

For balled trees, a hole, slightly larger than the diameter of the ball, is dug at the tree site (fig. 2–21). It should be deep enough but no deeper to allow the tree, after it has settled, to be at the same height it was in the nursery. If planted lower, the possibility of infection of the trunk by soil fungi, principally *Phytophthora* spp., is greater. After back-filling the hole three-quarters full, tamp it well, cut the twine holding the burlap around the trunk, fold the burlap into the hole, and complete filling and tamping. The lateral roots should branch near the soil surface, and the bud union should be well exposed. Immediately after planting, apply water to settle the soil, eliminate air pockets, and provide moisture to the root system (fig. 2–22). Basins around each tree, furrows down the tree row, or sprinklers directed at the base of the tree are methods used to provide water to newly planted trees.

The techniques of planting bare root trees are similar to those of balled trees except that the organization of the planting crew, the necessity of always keeping roots from drying, and the application of water are more critical. Larger holes are dug to accommodate the larger root system. The tree is set, the hole is partially filled with soil, and water is added so that wet soil may be worked around the root system. The hole is then completely filled, a basin is formed around the tree, and 5 to 10 gallons of water are put in the basin. During planting, care must be taken to ensure that the tree is at the same height or slightly higher than it was in the nursery. If adjustments in height are necessary, they must be done carefully so the root system will not be injured.

Opinions differ somewhat as to the advantage or disadvantage of defoliating bare root trees when they are planted, and successful plantings have been made with and without defoliation. Where bare root plantings are made in climates of low humidity, defoliation is usually practiced along with whitewashing to prevent sunburn. In more humid areas, on the other hand, defoliation is not considered necessary.

Studies on the effect of various anti-transpirant materials, sprayed on the foliage to reduce water loss from newly planted trees, have generally shown no beneficial results. Goren, Mendel, and Monselise (1962) found no favorable effects on tree survival when trees were sprayed with a polyvinyl acetate emulsion. In fact, they observed detrimental effects since undue reliance was placed on the anti-transpirant coating by many growers, and essential planting practices were neglected. Similarly, Fucik (1968), using an acrylic copolymer-type anti-transpirant spray on the foliage of Redblush grapefruit in Texas, found no apparent benefits eighteen months after transplanting.

Most soils have enough natural fertility to get the tree off to a good start. The addition of fertilizer in the planting hole is usually more damaging than beneficial and should be avoided. Some recently developed slow-release nutrients added to the soil when trees are planted have not resulted in damage, but their benefits have not been documented. On the other hand, the addition of nitrogenous organic manures and sludges to the planting hole have, in some instances, resulted in root disease problems (Carpenter *et al.*, 1959), although in South Africa it is recommended that 20 pounds of manure and 5 pounds of superphosphate be mixed in the planting hole (Malan, 1957).

In many areas, specialized equipment has been developed for efficient planting. Holes for trees are dug with power augers or mechanical cuppers, often equipped with a sweep to form a basin or water ring at the same time. Water tanks and portable tree-storage facilities to prevent root drying are sometimes used, particularly when planting bare root trees.

For many years, planting boards have been

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used to ensure that the tree is set in the exact location and at the correct height. These are 1- by 4-inch boards, 4 feet long, notched in the center and at each end. The center notch is placed at the stake marking the tree site and planting pegs are driven into the soil at each end of the board. The board is removed and the tree hole dug. The planting board is replaced so the end notches fit the planting pegs. The tree is then set in the hole with the trunk at the center notch and the tree no lower than it was in the nursery.

Many growers, rather than bother with the inconvenience of a planting board, rely upon a "good eye" to set the tree. Results in most cases are perfectly satisfactory.

Care of Newly-Planted Trees

After trees have been planted, there comes a period during which constant attention is required to assure their establishment. Because of their age, they are less able to withstand drought, cold, or heat, as well as the possible ravages of various pests and diseases. It is desirable that they grow rapidly to attain size and production potential as soon as possible. It is important, therefore, that they be given the best of care.

Irrigation.—Adequate irrigation, in most areas, is perhaps the most important cultural operation in the growth of trees. Even in high rainfall areas where irrigation is not generally practiced, drought periods following planting may result in a loss of trees if water is not supplied (Ochse *et al.*, 1961). Newly planted trees require water at frequent intervals, but in small amounts. Following the initial watering immediately after planting, the frequency of irrigation will depend upon soil, climate, and rainfall.

In California, newly planted trees may require water every four to five days in desert areas and every two or three weeks in districts of more moderate climate. In Florida, Lawrence (1962) recommends watering every two to five days (depending on rainfall) until trees become established. Other areas are comparable in the frequency of irrigation recommended (Hilgeman and Rodney, 1961; Bailey and Maxwell, 1963). Various types of irrigation methods are shown in figures 2–23 through 2–25. (See chap. 8 for a full discussion.)

Protecting the Tree.—Depending upon the area, the young tree often requires protection to prevent sunburn or cold damage. In citrus areas of the southwestern United States, it is standard practice to place "tree wraps" around the trunk

Fig. 2–23. Irrigation of newly planted trees by borders formed on each side of tree row.

Fig. 2–24. A drag-line sprinkler system used for irrigating young trees. The sprinkler head forms a fan of water directed at the base of the tree. As the trees grow, the fan will be replaced by a revolving head and the sprinklers placed in the middle, between four trees, to irrigate a larger area.

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Fig. 2–25. Young lemon trees in Arizona. Irrigation is by flooding between borders. A barley cover crop has been planted to prevent sand from blowing. Tree wraps and wind machines as well as flooding with water provide frost protection.

as soon as possible after planting to prevent sunburn. If light colored, opaque wraps are used, they also serve to suppress the growth of unwanted suckers on the trunk, provide protection from rabbits, and protect the trunk when using oil herbicides for weed control. Wraps made of lightweight cardboard or newspaper mat are satisfactory for this purpose. Often growers prefer to have the wraps serve also as cold protectors. While lightweight wraps afford some cold protection, it is best to use heavier insulated wraps. (fig. 2–26). If these are used, the trunk should be painted with Bordeaux mix before the rainy season, preferably when the wraps are applied, to prevent gummosis infection. The ties of any wraps should be inspected periodically to make sure they are not girdling the trunk.

Another method of cold protection for the young tree is the use of corn or cane stalks wrapped securely around the trunk and main scaffold branches of the tree. It is important that trees so wrapped have some exposed foliage so the tree will continue to function (fig. 2–27).

In Florida and Texas, young trees are protected from cold by banking the trunks and main scaffold limbs with trash-free soil (fig. 2–28). Insecticides are often added to prevent possible termite injury (Lawrence, 1962), or trunks are treated with an insecticide-fungicide banking paint (Young *et al.*, 1963). Permanent banks, made of a cylinder of wire mesh or roofing paper and filled with an insulating material such as rock wool or Fiberglas batts, are used by some growers in Texas (Young *et al.*, 1963; Hensz, 1966). These afford good protection but may harbor insects and rodents or induce trunk diseases by drying out too slowly after rains. Trials in Florida, however, have shown that permanent Fiberglas wraps were not as effective as soil banks (Reese, 1969).

Banks have not been used extensively in California since the hazard of trunk diseases is greater due to heavier, water-retaining soils and winter rainfall. In areas of sandy soils, however, they have been used successfully.

Fertilization.—The amount and kind of fertilization required by the newly-planted tree depends primarily upon the native fertility of the soil. In no case, however, is the amount great. Rather, the amount of fertilizer used at one time is small, but it is applied several times during the season. Generally, it is best to wait until the new tree shows signs of growth before adding fertilizer. To prevent root damage from burning it should be uniformly distributed in the basin or furrow.

In the alkaline soils of California and many other areas, the principal deficiency is that of nitrogen, which is generally applied in the form of an inorganic nitrogenous fertilizer such as calcium nitrate, ammonium sulfate, or ammonium nitrate. Since these materials are in a concentrated form, applications of one or two ounces at a time, two to four times during the season, are generally used. Zinc, and sometimes manganese, iron, and copper often become deficient in rapidly growing young trees. These elements, when needed, are normally applied in a micronutrient nutritional spray. Often, part of the nitrogen requirement may be satisfied by adding low-biuret urea to the nutritional spray. Boron is occasionally found deficient in some areas of central California where land has been heavily scraped in leveling (Opitz and Platt, 1967). The addition of one to two ounces of borax to soil around the young tree or the application of boron-containing manure is usually sufficient to correct this deficiency (Platt, 1968).

In sandy, acid soils of low native fertility, mixed fertilizers of lower concentration are used in slightly larger amounts but still in split applications. Nitrogen, phosphorus, potassium, and magnesium, as well as zinc, manganese, copper and boron, are often included in these mixes. In Florida, one pound of an 8–2–8 (N, P, K) fertilizer, plus

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Fig 2–26. Corrugated cardboard protectors for young trees. These provide protection against sunburn and cold.

Fig. 2–27. Young tree wrapped with corn stalks to provide cold protection to the trunk and scaffold branches. The top leafy branches are left exposed so photosynthesis may continue.

micronutrients, split in three applications, was found by Rasmussen and Smith (1962) to be effective during the first year.

Well-decomposed manures provide good nutrition to young trees if used in moderate amounts. Care must be taken to prevent them from contacting the trunk or damage may result. Also, unless well decomposed, they may tie up available nitrogen and cause a temporary deficiency in the soil. (See chap. 5.)

Protection Against Pests and Diseases.— Frequent inspection of young trees is advisable to be sure they are not damaged by various pests and diseases.

Rodents and rabbits are often numerous in orchards planted next to undeveloped land, and a concerted effort is needed to control them. Insects and mites may attack young trees and do severe damage unless they are controlled. If tree trunks are wrapped or banked for protection, periodic inspection is warranted to be sure diseases are not developing under the wrap or bank.

Weed growth around young trees should be removed to eliminate competition for water and nutrients. This may be done by hoeing or the

Fig. 2–28. A young tree in Florida banked with soil to protect the trunk from freeze injury.

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careful use of certain herbicides (see chap. 3). If oil is used as an herbicide, extreme care must be taken to prevent it from contacting the trunk. Some growers in California use mulches or spread black polyethylene sheets around young trees to control weeds.

Pests and control measures differ in different areas so local recommendations should be followed. To keep the tree healthy and free of pests is the goal of the successful grower.

Interplants and Intercrops

Interplanting with Citrus.—With certain exceptions, it is generally most satisfactory to plant citrus in solid blocks of one variety and one rootstock. If varieties are mixed, the different requirements of each for irrigation, pest control, and tree care make it more difficult and usually more expensive to provide the optimum care necessary for the best growth and production of each variety. In harvesting, the whole orchard must be covered to get the fruit from each variety.

Self unfruitful varieties, such as Clementine mandarin, Orlando and Minneola tangelos, and Fairchild, Fortune, and Page mandarin hybrids, require pollination from other varieties to assure good production. Where pollinators are needed, harvesting and spraying are made easier if they are planted in rows rather than scattered as individual trees throughout the orchard.

Some growers, unable to decide which variety or rootstock will be best for a certain area, alternate varieties or rootstocks when trees are planted. In such cases, trees in the row are set one half the normal distance apart and every other tree is removed when it is evident which variety or rootstock is best. A disadvantage of this practice is that often the decision to remove one variety is delayed too long and tree crowding results.

Interplanting with Perennial Crops.—Citrus interplanted with other tree crops has long been practiced in small orchards of countries in the Mediterranean area (Burke, 1961, 1962). Grapes, walnuts, olives, persimmons, and deciduous fruits are often mixed with citrus. Such orchards may also contain different varieties of citrus, and the various crops provide an income over a longer period of the year. Citrus is sometimes grown successfully in conjunction with date palms as illustrated by scattered plantings in North African oases and in some orchards of the Coachella Valley in California.

If citrus production is the prime consideration, however, mixed plantings are not apt to

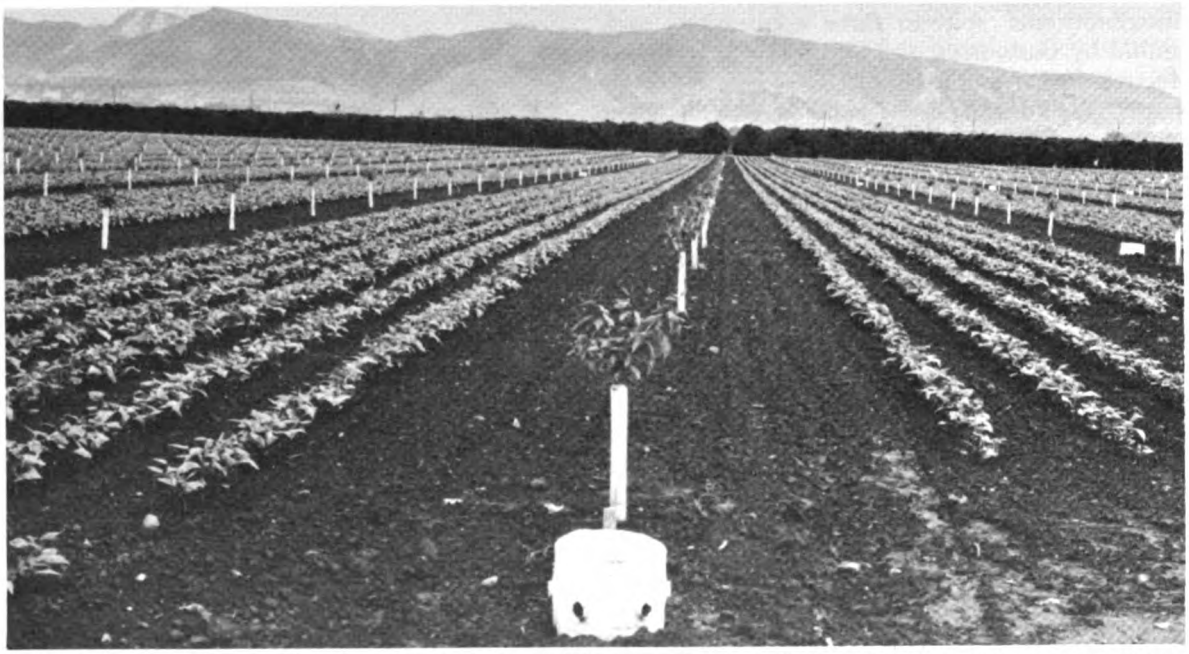

Fig. 2-29. An intercrop of lima beans planted between the rows in a young lemon orchard. Sufficient space is left on each side of the tree rows to prevent competition and allow for normal care of the citrus.

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provide maximum yields, since compromises in cultural care are usually necessary.

Intercrops.—Intercrops of quick-maturing annuals are sometimes used in young citrus orchards to provide a supplemental income while trees are developing. In California, lima or garbanzo beans are often used where the climate is suitable for their production (fig. 2–30). Flowers for seed production have also been grown successfully. In Israel, Gourstein (1954) suggests the use of potatoes, peanuts, and other intermediate crops as a source of revenue to cover part of the irrigation and cultivation expense.

Where these crops are used, it is important that their culture, particularly irrigation, be compatible with that of the citrus trees. Care must also be taken to be sure that pest control required for the intercrop does not upset the pest-control program for citrus. No intercrop should be planted so close to the trees as to cause competition for moisture and nutrients. Generally, an intercrop is advisable only during the first three or four years of the orchard's development. In growing the intercrop, the good of the orchard is the primary consideration and the intercrop must be considered secondary.

LITERATURE CITED

ALLEN, R. M., and J. B. CARPENTER. 1966. Arizona's cooperative citrus registration-certification program. Plant Dis. Rptr. **50**:145–149. (*Also:* Calif. Citrog. **51**:354, 362, 364, 366–67.)

ANONYMOUS. 1961. Planting citrus on "flatwoods" soils. Citrus. Indus. **42**(6):20–21.

BAILEY, M., and N. MAXWELL. 1963. Grove establishment. *In:* Maxwell, N. P., and M. A. Bailey (eds.). Guide for citrus production in the lower Rio Grande Valley. Pp. 16–17. Texas A. and M. Univ. Agr. Exp. St. and Agr. Ext. Serv. B-1002.

BAILEY, M., N. MAXWELL, D. CARTER, and D. HADDOCK. 1963. Selecting a site. *In:* Maxwell, N. P., and M. A. Bailey (eds.). Guide for citrus production in the lower Rio Grande Valley. Pp. 6–7. Texas A. and M. Univ. Agr. Exp. Sta. and Agr. Ext. Serv. B-1002.

BAINES, R. C., L. J. KLOTZ, T. A. DEWOLFE, and R. H. SMALL. 1966. Curb soil pests for profitable citrus trees. Calif. Citrog. **52**:3, 20, 22.

BATES, C. G. 1924. The windbreak as a farm asset. U. S. Dept. Agr. Farmers Bul. **1405**: 15 pp.

BEÑATENA, H. N., and A. R. PUJOL. 1965. The citrus budwood program in Concordia, Argentina. *In:* Price, W. C. (ed.). Proc. Third Conf. Intern. Org. Citrus Virol. Pp. 241–43.

BERNSTEIN, L. 1965. Salinity and citrus. Calif. Citrog. **50**:273–76.

BITTERS, W. P. 1964. Citrus cultural practices and production in Japan. Calif. Citrog. **50**:67–68, 70–75.

BLANCHARD, V. F. 1934. Depressing effects of wind on growth and yield of citrus trees. Calif. Citrog. **19**:206.

BOTHAM, J. R. 1963 (Rev.). Citrus growing in South Australia. Dept. Agr. So. Austral. Bul. **376**: 30 pp.

BRIDGES, G. D. 1967. Registered trees may make the difference. Citrus Indus. **48**(5):5, 7.

BROWN, L. N. 1962. Irrigation on steep land. Univ. Calif. Div. Agr. Sci. Circ. **509**: 26 pp.

——— 1963. Planting and irrigation on the contour. Univ. Calif. Div. Agr. Sci. Circ. **523**: 24 pp.

BURGER, W. P. 1967. Planting distances and the layout of citrus orchards. Farm. So. Africa **42**(12):9–13.

BURKE, J. H. 1952. The citrus industries of North Africa. U. S. Dept. Agr., For. Agr. Serv., For. Agr. Rpt. **66**: 152 pp.

——— 1958. Citrus industry of Brazil. U. S. Dept. Agr., For. Agr. Serv., For. Agr. Rpt. **109**: 33 pp.

——— 1961. Citrus industry of Spain. U. S. Dept. Agr., For. Agr. Serv., For. Agr. Rpt. **56**:54 pp.

——— 1962. (Rev.). Citrus industry of Italy. U. S. Dept. Agr., For. Agr. Serv., For. Agr. Rpt. **59**: 79 pp.

CAMP, A. F. 1957. Planting and care of young citrus trees. *In:* Citrus industry of Florida. Fla. Dept. Agr., Tallahassee. Pp. 100–11.

CARPENTER, J. B., L. J. KLOTZ, T. A. DEWOLFE, and M. P. MILLER. 1959. Collapse of young trees in Coachella Valley. Calif. Citrog. **45**:4, 19–21.

CHEN, Z., and A. P. DRAGAVCEV. 1958. Fruit growing on embankments in China. Priroda **47**(11):95–96.

FORD, H. W., and W. F. SPENCER. 1962. Combatting iron oxide deposits in drain tiles. Proc. Fla. State Hort. Soc. **75**:27–32.

FUCIK, J. E. 1968. The use of an anti-transpirant on newly-set grapefruit trees. Jour. Rio Grande Val. Hort. Soc. **22**:42–45.

GAGNARD, J., and G. MOLIN. 1956. La Technique de transplantation des arbres à feuilles persistantes peut-elle être améliorée? (Can the technique of transplanting evergreen trees be improved?) Fruits et Prim. **26**:333–34.

GARDNER, F. E., and G. E. HORANIC. 1959. Relation of citrus nursery tree size from ¼ to ⅞ inches to ultimate size and production. Proc. Fla. State Hort. Soc. **72**:102–05.

GONZALEZ-SICILIA, E. 1968. El cultivo de los agrios. Editorial Bello, Valencia, Spain. 814 pp.

GOREN, R., K. MENDEL, and S. P. MONSELISE. 1962. Effect of polyvinyl coating on survival of transplanted citrus nursery stock under experimental and commercial conditions. Proc. Amer. Soc. Hort. Sci. **81**:231–37.

GROVER, B. L., G. A. CAHOON, and C. W. HOTCHKISS. 1964. Moisture relations of soil inclusions of a texture different from the surrounding soil. Soil Sci. Soc. Amer. Proc. **28**:692–95.

GOURSTEIN, B. 1954. The development of citrus planting and cultivation methods. Economic News [Israel] **6**:25–29.

GRIMM, G. R. 1957. Factors affecting dieback and growth responses of young transplanted citrus trees. Proc. Fla. State Hort. Soc. **70**:82–85.

HENSZ, R. A. 1966. Fiberglas batts are superior for banking. Texas Farm. and Citricult. **43**:7, 22.

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HILGEMAN, R. H., and D. R. RODNEY. 1961. Commercial citrus production in Arizona. Univ. Ariz. Agr. Exp. Sta. and Coop. Ext. Serv. Spec. Rpt. No. 7: 31 pp.

HODGSON, R. W. 1962. The Japanese mandarin orange industry. Calif. Citrog. 47:171–73.

HOUSTON, C. E. 1967. Drainage of irrigated land. Univ. Calif. Div. Agr. Sci. Circ. 504 (Rev.): 40 pp.

HOUSTON, C. E., and R. O. SCHADE. 1966. Irrigation return-water systems. Univ. Calif. Div. Agr. Sci. Circ. 542: 8 pp.

JOHNSTON, J. C. 1953. Citrus growing in California. Univ. Calif. Div. Agr. Sci. Circ. 426: 43 pp.

KETCHIE, D. O., and J. R. FURR. 1968. Sunburn and heat injury of citrus. Calif. Citrog. 53:252, 270–73.

KETCHIE, D. O., and A. L. BALLARD. 1968. Environments which cause heat injury to "Valencia" oranges. Proc. Amer. Soc. Hort. Sci. 93:166–72.

KLOTZ, L. J., T. A. DEWOLFE, L. C. ERICKSON, L. B. BRANNAMAN, and M. J. GARBER. 1962. Twig dieback of citrus trees. Calif. Citrog. 47:74, 86, 88, 90–91.

KLOTZ, L. J., T. A. DEWOLFE, D. O. ROSEDALE, and M. J. GARBER. 1960. Disinfestation of some planting sites improves growth of navel orange trees on Troyer citrange rootstock. Plant Dis. Rptr. 44: 309–11.

LARUE, R. G., and M. B. ROUNDS. 1948. Planning and planting the orchard. *In:* Webber, H. J., and L. D. Batchelor (eds.). The citrus industry. II:259–99. Univ. Calif. Press, Berkeley and Los Angeles.

LAWRENCE, F. P. 1958. Selecting a grove site. Univ. Fla. Agr. Ext. Serv. Circ. 185: 4 pp.

——— 1961. Planting and care of young citrus trees. Citrus Indus. 42(5):7, 9–10.

——— 1962. Planting and care of young citrus. Univ. Fla. Agr. Ext. Circ. 238: 22 pp.

——— 1968. Hazards of planting unregistered trees. Citrus Indus. 49(8):24.

LEWIS, L. N., C. D. MCCARTY, and L. W. CRIM, 1962. Planting distances in orange groves. Calif. Citrog. 47:75, 84–86.

LOMBARD, T. A. 1950*a*. Eucalyptus windbreaks vs. lemon production. Calif. Citrog. 35:301.

——— 1950*b*. Valencia orange tree spacing experiment. Calif. Citrog. 35:397.

MCCARTY, C. D. 1966. High density planting. Calif. Citrog. 51:91, 110, 112, 114–15.

MCCARTY, C. D., S. B. BOSWELL, K. W. HENCH, and T. M. LITTLE. 1968. Minimum temperatures—hedgerow vs. open-planted citrus. Calif. Citrog. 53:438, 453–54.

MCCARTY, C. D., G. K. BROWN, and P. F. BURKNER. 1968. Designing tree and orchard for mechanical harvest. Calif. Citrog. 53:251, 260, 262, 264–68.

MALAN, E. F. 1957. Planting and care of citrus trees. Farm. So. Africa 33(6):42–43, 45–46.

MATHER, S. M. 1964. Progress report on registration and certification of California citrus trees. Calif. Citrog. 50:4, 12, 15–18.

MENDEL, K. 1940. Seedling size as a criterion for the selection of sweet lime stocks. Hadar 13(2):40–48.

METCALF, W. 1936. The influence of windbreaks in protecting citrus orchards. Jour. Forestry. 34:571–80.

MILLER, M. P. 1968. Bare root planting can be successful in California. Calif. Citrog. 53:332, 343–44.

MONSELISE, S. P. 1951. Light distribution in citrus trees. Bul. Res. Coun. Israel. 1(3):36–53.

MYERS, V. I., P. E. Ross, and D. L. CARTER, 1963. Irrigation, salinity and drainage. *In:* Maxwell, N. P., and M. A. Bailey (eds.). Guide for citrus production in the lower Rio Grande Valley. Pp. 8–11. Texas A. and M. Univ. Agr. Exp. Sta. and Agr. Ext. Serv. B–1002.

NELSON, A. E. 1940. Florida freeze—some first hand observations. Calif. Citrog. 25:248, 276.

NORRIS, R. E. 1961. Tree spacing and thinning. Citrus Indus. 42(9):13–16.

——— 1962. Thinning practices in Florida citrus groves. Univ. Fla. Agr. Ext. Serv. Circ. 228:14 pp.

OCHSE, J. J., M. J. SOULE, JR., M. J. DIJKMAN, and C. WEHLBURG. 1961. Tropical and subtropical agriculture. Vol. I. Macmillan Co., N. Y. 760 pp.

OLSON, E. O. and B. SLEETH. 1965. Release to Texas growers of citrus budwood of virus-indexed selections of 11 varieties. Jour. Rio Grande Val. Hort. Soc. 19: 17–19.

OPITZ, K. W. 1964. Pointers on planting or buying a central California grove. Calif. Citrog. 49:203–205.

OPITZ, K. W., and R. G. PLATT. 1967. Boron deficiency in central California. Calif. Citrog. 52:474.

——— 1969. Citrus growing in California. Univ. Calif. Div. Agr. Sci. Manual 39: 58 pp.

PARKER, E. R. 1948. Selection of orchard site. *In:* Webber, H. J., and L. D. Batchelor (eds.). The citrus industry. II:223–58. Univ. Calif. Press, Berkeley and Los Angeles.

PATT, Y. 1953. Results of citrus grove thinning by uprooting trees. State of Israel, Min. of Agr., Agr. Res. Sta. Bul. 60:36–45.

PEHRSON, J. E. 1964. Windbreaks don't take long. Calif. Citrog. 49:336.

PHILLIPS, R. L. 1969. Performance of closely spaced trees. Proc. Fla. State Hort. Soc. 82:48–51. [Also Citrus Indus. 51(7):9–11.]

PLATT, R. G. 1958. Leaf drop, fruit drop, twig dieback. Calif. Citrog. 43:192, 207–09.

——— 1965. Look before you leap into citrus. Calif. Citrog. 51:45, 59, 61, 63.

——— 1966. Windbreaks for citrus. Calif. Citrog. 51: 396–97, 418, 420–21.

——— 1966. Planting the orchard. Calif. Citrog. 52:53, 67–68, 72.

——— 1968. Micronutrient deficiencies of citrus. Univ. Calif. Div. Agr. Sci. Leaf. 115 (Rev.).

RASMUSSEN, G. K., and P. F. SMITH. 1962. Evaluation of fertilizer practices for young orange trees. Citrus Indus. 43(9):16–19.

REED, H. S., and E. T. BARTHOLOMEW. 1930. The effects of desiccating winds on citrus trees. Univ. Calif. Col. of Agr. Bul. 484: 59 pp.

REESE, R. L. 1969. Soil banks or Fiberglas wraps for young citrus trees? Citrus Indus. 50(1):17, 19–20.

REUTHER, WALTER, E. C. CALAVAN, E. M. NAUER, and C. N. ROISTACHER. 1968*a*. Citrus variety improvement program provides wide benefits, I. Calif. Citrog. 53: 205, 222–24, 226, 228.

——— 1968*b*. Citrus variety improvement program provides wide benefits, II. Calif. Citrog. 53:275–78.

ROCK, R. C. 1969. The citrus profit formula. Calif. Citrog. 54:127, 150, 152, 154.

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ROSEDALE, D. O. 1967. Strip weed control in San Diego County. Calif. Citrog. **52**:438–39.

ROSSETTI, V., A. A. SALIBE, A. F. CINTRA, S. BONILHA, and D. ARMBRUSTER. 1965. The citrus budwood certification program in the state of São Paulo. *In:* Price, W. C. (ed.). Proc. Third Conf. Intern. Org. Citrus Virol., Pp. 235–40.

SAVAGE, Z. 1959. Some considerations regarding setting distances. Proc. Fla. State Hort. Soc. **72**:79–83. (Also: Citrus Mag. **22**(4):18–19, 28–29, 32.)

——— 1962. So you would like to set a citrus grove? Citrus Indus. **43**(11):29.

SCHADE, R. O. 1966. Cooling citrus with overhead sprinklers. Calif. Citrog. **51**:478.

——— 1967. Return flow systems in central California. Calif. Citrog. **52**:180.

UZZIEL, M. 1953. Windbreaks for citrus groves. (Hebrew) Hassadeh **34**:94–96.

WAHLBERG, H. E. 1941. Windbreaks for orchard protection. Calif. Citrog. **26**:359, 372–73.

WILCOX, L. V. 1958. Water quality from the standpoint of irrigation. Jour. Amer. Water Works Assoc. **50**(5): 650–54.

YOUNG, F. D. 1926. Desert winds and windbreak protection. Calif. Citrog. **11**:455, 484–87.

——— 1927. Windbreaks' effectiveness in southern California orchards. Calif. Citrog. **12**:424.

——— 1933. Desert winds in southern California and their effect on citrus trees. Citrus Leaves **13**(3): 16–18.

——— 1940. Frost and the prevention of frost damage. U. S. Dept. Agr. Farm. Bul. **1588**: 65 pp.

YOUNG, R., P. HOBGOOD, N. P. MAXWELL, and D. HADDOCK. 1963. Cold protection. *In:* Maxwell N. P., and M. A. Bailey (eds.). Guide for citrus production in the lower Rio Grande Valley. Pp. 31–40. Texas A. and M. Univ. Agr. Exp. Sta. and Agr. Ext. Serv. B–1002.

ZIEGLER, L. W., and H. S. WOLFE. 1961. Citrus growing in Florida. Univ. Fla. Press, Gainesville, Fla. 248 pp.

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CHAPTER 3

Weed Control in Citrus

L. S. JORDAN and B. E. DAY

THERE ARE NUMEROUS REASONS for weed control in citrus orchards: weeds compete with citrus trees for water and nutrients; they compete with trees in young orchards for light; they harbor insects, diseases, and rodents which attack trees; they interfere with orchard management and harvesting operations; and under certain conditions, they may increase frost hazard. In some instances, weed competition directly reduces both quality and yield of harvested fruit.

Permanent eradication of weeds in citrus orchards is rarely economically feasible or practical. The desired level of weed control must depend upon the cost of weed-caused losses in relation to the cost of control methods and produce value. The objective of weed-control programs, whether they involve direct plant destruction or prevention of reproduction, is to reduce or eliminate their undesirable effects on crop plants. Methods of accomplishing these objectives and the amount of weed control required vary with local soil and climate conditions as well as with the life cycles, population levels, and methods of reproduction of weed species present in an orchard.

LOSSES FROM WEEDS

Economic losses caused by weeds in citrus orchards are difficult to assess. Losses from water and fertilizers used by weeds are undoubtedly substantial. Weed competition with young trees can be severe and reduce growth significantly. Most weeds cannot compete successfully with mature trees for space, but they can reduce fruit production by competing for nutrients and water. In addition, rodent, insect, and disease damage to trees is often far more severe in orchards infested with weeds which either protect or serve as alternate hosts of these pests. In a recent report, the Agricultural Research Service of the U. S. Department of Agriculture estimated that weeds reduce citrus production in the United States by approximately 5 per cent (table 3–1).

In 1964, citrus growers in California, for example, spent an estimated $27 per acre, or over $6.3 million to control weeds on 242,360 acres. Despite these expenditures, losses from weeds in citrus orchards for 1964 were still estimated at $68 per acre, or over $16 million. Thus, the total cost of both control measures and losses in citrus for one year was over $23 million (Anon., 1964).

WEED CLASSIFICATION

From the standpoint of control, weeds can be classified in two ways. One classification is

Table 3–1
ESTIMATED AVERAGE ANNUAL LOSSES DUE TO WEEDS, 1951–60

Commodity	Loss From Potential Production		
	Per Cent of Loss	Quantity (In Thousand Tons)	Value (In Thousand Dollars)
Grapefruit	5	87	2,549
Lemons	5	33	2,227
Oranges	5	286	16,066

Source: Adapted from U. S. Department of Agriculture, Agricultural Research Services Handbook No. 291 (1965), p. 61.

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based on the life cycle of plants and groups weeds as annuals, biennials, and perennials. The other is based on the weed's botanical subclass.

Life Cycle Classification

Most annual weeds reproduce only from seed and complete their life cycle in one season or year. Biennials germinate and produce vegetative growth during the first season, produce seed after winter dormancy, and die during the second season. Weeds germinating in the fall produce seed the following spring or summer and are called winter annuals. Many biennials assume the life cycle of winter annuals in subtropical citrus-growing regions. On the basis of control, biennials may be grouped with annuals since both have a determinate life span, are self-destroying, and propagate by seeds. Control objectives are to prevent both growth of the above-ground portion of the weed and seed production.

Many annual weed species are prolific seed producers. Seed production by perennial weeds is quite variable, ranging from essentially no viable seeds to many thousand per plant. Some weed seeds may lie dormant in soil for many years before germination and are always a potential source for reinfestation of the field.

Perennial weeds live for three or more years and vary in their reproductive habits. Simple perennials reproduce from seed only, and rarely vegetatively. Most noxious perennials, however, are more complex and reproduce vegetatively by means of roots, stolons, rhizomes, bulbs, or tubers. Complex perennials regrow after tops are removed, and control measures, therefore, must be designed to destroy underground vegetative organs.

Botanical Subclass Classification

Weeds are also sometimes classified by botanical subclass into monocotyledonous (grasses) or dicotyledonous (broadleaf) species. These classifications are useful where selective chemical control is dependent upon morphological differences. Some herbicides—2,4-D, for example[1]—are more toxic to broadleaf species than to grasses, while other herbicides such as dalapon control grasses more readily than they do broadleaf species.

Citrus Weed Problems

Some of the common weeds found in citrus orchards in the major production areas of the United States are shown in table 3-3.[2] The table does not include all weeds found in citrus orchards, because orchard flora usually contain most weed species present in the surrounding cultivated land of the region. The composition of weed flora in citrus orchards varies with each production region based on species adaptation to climatic and edaphic conditions.

Annuals and summer-growing perennials predominate in arid subtropical orchards. If no perennials are present, summer- and winter-growing annuals grow and die alternately during the year. Introduction of perennials, such as bermudagrass or nutsedge, leads to reduction of annual weeds, and especially of summer annuals. At the same time, control becomes more difficult.

Orchards in semitropical regions are infested with annual grasses and broadleaf weeds, but perennial grasses and vines become more important. The occurrence of a large variety of perennial species makes weed control very difficult. It also makes the consequences of poor weed control more damaging to citrus production.

The worst problems in citrus production occur in humid tropical regions. Perennial grass and broadleaf species compete with orchard trees throughout the year, resulting in reduced quality and yield. The common practice of weed removal with machetes and hoes is laborious, expensive, only partially successful in reducing competition, and potentially injurious to trees; at best, it only reduces the weed infestation without eliminating it. The injury it causes may, in turn, lead to secondary infections by disease organisms.

Reuther (1969) reports that most mature citrus orchards in humid tropical areas support heavy growth of epiphytic plants such as bromeliads, orchids, lichens, and felt fungi which use the tree for support but do not invade the host tree's tissue (see chap. 9, page 285). Epiphytes interfere with tree vigor directly by limiting light to leaves and indirectly by reducing ventilation and fostering pests and disease organisms. Lichens provide moist conditions favorable for invasion by various mistletoe (Loranthaceae) spe-

[1] Common and chemical names of herbicides mentioned in this chapter are listed in table 3-2. Common names will be used in the text.

[2] Common and botanical names of weeds mentioned in this chapter are listed in table 3-3. Common names will be used in the text.

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Table 3–2
COMMON AND CHEMICAL NAMES OF HERBICIDES

Common Name	Chemical Name
Amitrole	3-amino-*s*-triazole
Atrazine	2-chloro-4(ethylamino)-6-(isopropylamino)-*s*-triazine
Bromacil	5-bromo-3-*sec*-butyl-6-methyluracil
Cacodylic acid	Hydroxydimethylarsine oxide
Dalapon	2,2-dichloropropionic acid
Dichlobenil	2,6-dichlorobenzonitrile
Dinoseb	2-*sec*-butyl-4,6-dinitrophenol
Diquat	6,7-dihydrodipyrido [1,2-*a*:2′,1′-*c*] pyrazinedium ion
Diuron	3-(3,4-dichlorophenyl)-(1,1-dimethylurea)
DSMA	Disodium methanearsonate
Fluometuron	1,1-dimethyl-3-(*a,a,a*-trifluoro-*m-tolyl*) urea
Metham	Sodium methyldithiocarbamate
Methylbromide	Methylbromide
Monuron	3-(*p*-chlorophenyl)-1,1-dimethylurea
MSMA	Monosodium methanearsonate
Paraquat	1,1′-dimethyl-4,4′-bipyridinium ion
PCP	Pentachlorophenol
Silvex	2-(2,4,5-trichlorophenoxy) propionic acid
Simazine	2-chloro-4,6-bis(ethylamino)-*s*-triazine
Terbacil	3-*tert*-butyl-5-chloro-6-methyluracil
Trifluralin	*a,a,a*-trifluoro-2,6-dinitro-*N,N*-dipropyl-*p*-toluidine
2,4-D	(2,4-dichlorophenoxy)acetic acid
2,4,5-T	(2,4,5-trichlorophenoxy)acetic acid
Wydac	3′,4′,-dichloropropionamide
	n-methyl-1-naphthylcarbamate 5%

cies. Mistletoes are semiparasites which derive most of their moisture and mineral nutrients and some of their energy food from the host plant. If mistletoe is not controlled, the tree becomes nonproductive.

METHODS OF WEED CONTROL

Successful weed-control programs depend upon knowledge of the reproductive habits and distribution methods of predominant weed species. Seeds and fruit of many weeds are modified for dispersal by wind, water, or animals. Growers introduce and spread weeds in manures and mulches, in nursery stock, and on farm machinery. Tubers, bulbs, and root and stem cuttings are also spread and replanted by cultivation equipment. As a result, there are many methods of weed control adapted to specific weed situations. These include burning, flooding, grazing, competitive cropping, smothering, hand and mechanical tillage, mowing, and using biological and chemical agents.

General Methods

Weed control with hand tools is practiced to a large scale in some citrus-production regions of the world, and is especially prevalent in tropical orchards. Considering the amount of human labor involved, weed control with hoes and machetes is not efficient when more than a few trees are involved. Too often the operation cannot be properly timed and is ineffective in reducing weed competition with trees, especially during the first three to four years after planting. Reuther[3] reports that wounds inflicted by hand tools on the trunks and crown area provide a ready entry for disease organisms. Removal of soil surrounding the trunk incident to hoeing often produces a depression in which water collects. Standing water fosters the development of many fungi and increases their chance of invading the trunk in the wetter areas.

Burning is sometimes employed for land preparation prior to planting orchards, and is particularly common in the tropics. It is hazardous in established orchards because tree damage may occur if large amounts of fuel are available. Burning with oil or gas fuels is not widely practiced in citrus orchards.

Competitive cropping is often beneficial in reducing weeds in young orchards, although

[3] Personal communication from Walter Reuther, Department of Plant Sciences, University of California, Riverside.

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Table 3–3
COMMON AND BOTANICAL NAMES OF WEEDS IN CITRUS ORCHARDS

Common Name	Botanical Name
Bahiagrass	*Paspalum notatum* Fluegge
Balsamapple	*Momordica charantia* L.
Barnyardgrass	*Echinochloa crusgalli* (L.) Beauv.
Bermuda buttercup	*Oxalis cernua* Thunb.
Bermudagrass	*Cynodon dactylon* (L.) Pers.
Black nightshade	*Solanum nigrum* L.
Burclover	*Medicago* spp.
Burning nettle	*Urtica urens* L.
Carelessweed	*Amaranthus palmeri* (S.) Wats.
Chickweed	*Stellaria media* (L.) Cyrillo
Common lambsquarters	*Chenopodium album* L.
Common mallow	*Malva neglecta* Wallr.
Common purslane	*Portulaca oleracea* L.
Common ragweed	*Ambrosia artemisiifolia* L.
Cudweed	*Gnaphalium* spp.
Dog fennel	*Eupatorium capillifolium* (Lam.) Small
Field bindweed	*Convolvulus arvensis* L.
Foxtail	*Setaria* spp.
Goatweed	*Scoparia dulcis*
Guineagrass	*Panicum maximum* Jacq.
Johnsongrass	*Sorghum halepense* (L.) Pers.
Large crabgrass	*Digitaria sanquinalis* (L.) Scop.
Little mallow	*Malva parviflora* L.
Lovegrass	*Eragrostis* spp.
Maypop passionflower	*Passiflora incarnata* L.
Milkweed vine	*Morrenia ordorata* Lindl.
Moonflower vine	*Calonyction aculeatum* House
Morningglory, annual	*Ipomea* spp.
Mustards, annual	*Brassica* spp.
Pangoloagrass	*Digitaria decumbens* Stent.
Paragrass	*Panicum purpurascens* Raddi
Precatory bean, Rosary pea	*Abrus precatorius* L.
Prostrate pigweed	*Amaranthus graecizans* L.
Prostrate spotted spurge	*Euphorbia maculata* L.
Prostrate spurge	*Euphorbia supina* Raf.
Puncturevine	*Tribulus terrestris* L.
Purple nutsedge	*Cyperus rotundus* L.
Redroot pigweed	*Amaranthus retroflexus* L.
Sandbur	*Cenchrus* spp.
Shepherdspurse	*Capsella bursa-pastoris* (L.) Medic.
Spanishneedles	*Bidens bipinnata* L.
Spreading pigweed	*Amaranthus blitoides* (S.) Wats.
Subterranean clover	*Trifolium subterraneium* L.
Torpedograss	*Panicum repens* L.
Vaseygrass	*Paspalum urvillei* Steud.
Virginia creeper	*Parthenocissus quinque folia* (L.) Planch.

weed control is rarely the primary objective of such practices. Cropping between rows is practiced in areas where maximum food production is desired. The crops themselves compete with trees for water and nutrients, and their principal advantages are not only the production of food or fodder between tree rows but also the prevention of soil erosion. Weed-control methods under these conditions are often dependent upon the companion crop and not upon citrus tree requirements. Growth of highly competitive crops in orchards will generally reduce citrus growth and production, but as long as the value of plants grown with citrus is greater than the increased citrus production without the companion plants, they cannot rightfully be considered weeds.

Smothering with straw, sawdust, or other mulches provides some control of weed establishment from seed, but is ineffective against established perennials. Smothering with plastic sheets or tarpaper is effective only for the control of small infestations of perennial weeds.

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Biological control of weeds by parasites and diseases functions to some extent in all weedy orchards. Present knowledge is insufficient to permit growers to beneficially introduce or manage biological control agents. Grazing by geese, swine, or other animals is effective against certain palatable weeds, but the animals are difficult to properly manage in orchards and are more or less destructive to the trees. Another disadvantage is that unpalatable weeds become dominant.

Mowing, tillage, and treating with chemical herbicides are the three primary weed-control methods used in citrus. Each method has its advantages and disadvantages. Deciding on which one to use depends on the weed problems and orchard conditions, and it is often best to use a combination of methods.

Mowing

Mowing is quite widely used in orchards where cultivation or other forms of noncultivation are not practicable. It offers few advantages in itself as a weed-control method and is justified where a cover crop is desired on hillsides and other sloping land to prevent soil erosion, or during high rainfall periods when soil-moisture conservation is not necessary or even desirable. Two immediate advantages are that mowing is easily performed and that a mowed orchard's appearance is pleasing.

Weed control by mowing is useful against tall-growing weed species; low-growing prostrate species have an overwhelming competitive advantage. Mowed orchards in many areas rapidly develop a solid stand of perennial grass which becomes the stable vegetation, and the orchards are thus converted to a sod culture (see chap. 4). It is desirable to maintain low-growing shallow-rooted species which provide minimum competition with trees for water and nutrients. Even frequent mowing, however, will not sufficiently decrease water consumption by perennial grass, especially under drought conditions. Leyden (1969) observed in Texas that one more irrigation a year is required with sod cultures than with clean cultivation. Yield and growth of trees are reduced by sod cultures, in which grass competes with trees for nutrients, in comparison with clean cultivation and chemical weed control (Leyden, 1969). Gophers and field mice are not only harder to detect and control, but they cause more tree damage in mowed orchards. Mowing is best practiced between tree rows and away from trees, and in combination with herbicide applications along the row in the tree's root zones where soil erosion is the problem (Ryan, 1969).

Tillage

Machine cultivation is used to control weeds in many citrus orchards because it has the advantage of being easily and rapidly performed with equipment which is usually available. Timing of cultivation for annual weed control is not as critical as with soil-active herbicides. Annual weeds are killed efficiently and economically by severing stems from roots before flowering while weeds are still young. Thus, each crop of weeds must be killed in order to minimize competition with trees and seed production.

When seeds are produced, however, they are incorporated into soil during the next cultivation where some remain viable for many years. Each cultivation also brings seeds from the subsurface to the soil surface where they can germinate. Then, if environmental conditions are right, a new weed crop is produced. This sequence of cultivation followed by weed seed germination may continue indefinitely, and the number of cultivations required is determined by the number of flushes of weed emergence.

Tillage at proper time intervals can be used to kill deep-rooted perennials by ultimately exhausting their underground food reserves. Stored food is consumed in the process of sending new shoots to the surface after each cultivation, and these shoots may continue to withdraw food reserves for a week or more after they emerge. When sufficient foliage has developed, food reserves are replenished by photosynthetic products. Cultivation, therefore, is most effective at the time of maximum net food depletion.

Simple perennials are often killed in one season by properly-timed tillage. Deep-rooted rhizomatous, tuberous, or bulbous weeds with massive food reserves are killed only after a rigorously-maintained program of cultivation of two or more years' duration.

Control of resistant perennials in citrus orchards is rarely achieved by cultivation. Rainy periods or the necessity of maintaining a proper irrigation schedule result in interruptions in tillage, enabling weeds to replenish food reserves. Thus, although infrequent tillage provides temporary weed control, it spreads and invigorates perennial weeds by increasing the number of buried weed seeds and widely distributing rhi-

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zome and stolon cuttings, tubers, and bulbs. Infrequent tillage results in establishing solid stands of aggressive, resistant species such as johnsongrass, bermudagrass, and nutsedge.

With most soils, constant cultivation is damaging to soil tilth, causes soil compaction, and results in the formation of a plow sole which retards penetration of water (Anon., 1964; Kimble, Wallace, and Mueller, 1950; E. C. Moore, 1944, 1945; P. W. Moore, 1944, 1946). Injury to tree trunks and roots provides an easy avenue for infestation by disease organisms. Tree feeder roots which normally grow in the soil's disturbed layer are repeatedly destroyed by cultivation, and for all practical purposes, the cultivated layer of the soil is of no use to the tree. Thus, for shallow-rooted trees, such as those growing in bedded groves in the Indian River area of Florida, cultivation is undesirable.

Soil erosion is frequently a problem in cultivated orchards. Freshly cultivated soil moves readily with water; therefore, during rainy seasons or before irrigation, tillage should be practiced with care. Planting orchards on terraces or contoured hillsides reduces cultivation-induced erosion. Where feasible, combinations of mowing, or sod culture, and chemical weed control should be used to reduce soil compaction and erosion in orchards.

Herbicides

Chemical weed control in citrus is widely accepted and continues to increase in the United States. The weed-control principles in citrus-orchard management do not differ greatly from those in other tree crops. Nontillage in combination with oil sprays for weed control has been practiced continuously in California for over thirty years (Johnston and Sullivan, 1949; Day and Jordan, 1967), and was virtually the only acceptable treatment until 1955, when monuron was registered and recommended for annual weed control in citrus orchards (Day, 1955). Subsequently, other chemicals, including bromacil, dinoseb, diuron, simazine, and paraquat have become extensively used for the same purpose (Day and Jordan, 1969). Herbicides have also been developed recently for weed control in Texas, Florida, and other major world citrus areas, and it is significant that citrus is relatively tolerant to orchard applications of many of the available chemicals (Day, 1955; Day and Jordan, 1969; Goren and Monselise, 1969; Herholdt, 1969; Jackson, 1970; Kretchman, 1962; Leyden, 1969; Oohata, 1969; Phillips, 1970; Ryan, 1969; Ryan and Kretchman, 1968; Torrisi, 1969; Turpin *et al.*, 1970). There are now more than one hundred commercial herbicides being marketed in thousands of different combinations and formulations, and under hundreds of brand names.

Selectivity.—The basis for agricultural use of herbicides is selectivity—a chemical's ability to kill one plant and not another. All herbicides are selective to some extent, and each herbicide category includes both highly selective and relatively nonselective chemicals. Selectivity is never absolute, and must take into account formulation, dosage, method of application, and effects of local environmental conditions. It may result from several factors, including differences in the biochemistry of plant species, the herbicide's failure to translocate in tissues of certain plants, and metabolism by resistant plants. Selectivity may also be achieved through chemical placement, either by localizing the herbicide in the soil surface above root level of citrus trees, or spraying an herbicide directly on weeds rather than on trees which may be damaged by such sprays.

Each selective herbicide has its susceptible crops and weeds. Typically, susceptibility follows taxonomic family lines; but there may be some varieties within each species that are more or less tolerant than others. Since the only common characteristic of herbicides is their ability to kill plants, crop plants cannot be expected to be much more resistant than taxonomically-related weeds which are susceptible to these chemicals. Thus, no single chemical will provide complete selective weed control in all situations in citrus orchards. For this reason, chemical weed-control programs must be adapted to local weed flora as well as to environmental, soil, and other conditions, and these programs usually require using a combination or alternation of various treatments.

Because selectivity, too, often follows taxonomic lines, it is likely that all close relatives of a resistant or susceptible weed species will react similarly to an herbicide. Chemical weed control is, therefore, difficult in infested crops whose family or genus is the same as that of the weed species. Fortunately, weeds of citrus orchards are not closely related to citrus. The commercial species and varieties of both citrus root stocks and scions are similar in response to herbicides, and experience gained with one species or variety is generally applicable to others. This does not preclude the possibility of developing a root stock or

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scion which has a different response to herbicides. Likewise, a new herbicide could feasibly be developed which could react selectively with different root stocks and scions.

Herbicides employed in citrus orchards are applied either before or after weed emergence. Pre-emergence herbicides are soil-active, controlling weeds germinating from seeds for a period of a few weeks to over a year. Post-emergence contact or translocated herbicides are foliar-active, controlling each flush of weed growth after emergence. Some herbicides are foliar- *and* soil-active and can be used to control both emerged seedlings and germinating seeds. There is usually no residual activity of contact herbicides for controlling successive crops of weeds.

Post-emergence Herbicides.—Contact herbicides serve as a "chemical hoe," killing only plant parts wet by spray. Since they perform the same function, they may replace cultivation. But unlike cultivation, they do not disturb the soil. Some of these herbicides are petroleum weed oils, oils fortified with dinoseb or PCP, and water solutions of paraquat, DSMA, MSMA, cacodylic acid, and dinoseb. A single spraying with a contact herbicide kills most annual weeds, but a series of treatments are required for perennial weed control. When succeeding flushes of regrowth are killed, underground food reserves become exhausted and the weed finally dies.

Weed oils are petroleum oils refined to enhance their herbicidal properties. They are not pure chemicals, but rather complex mixtures which concentrate a maximum of phytotoxic components within a viscosity, density, and boiling range permitting convenient handling and application. The greatest phytotoxicity is associated with oils high in aromatic content. Diesel fuel and other fuel oil grades are not efficient herbicides, but they may be made so by fortification with oil-soluble herbicides such as emulsifiable dinoseb and PCP. The amount of active ingredients in a commercial formulation is variable, and the user should carefully follow label instructions in mixing.

Weed oil is being replaced by water-soluble herbicides such as paraquat, the organic arsenicals, and dinoseb formulations with minimal amounts of oil. The latter are not only easier to handle, store, and spray, but they are also less injurious to the tree when sprayed on the trunk. They should not, however, be applied to green tree tissue, because it is highly susceptible to injury from contact sprays.

Some California citrus orchards have been maintained weed-free for years with no evident detrimental effects on trees. Weed oil, fortified weed oil, diquat, paraquat, DSMA, MSMA, cacodylic acid, and dinoseb are contact sprays that may be used in citrus orchards without injuring trees. Weed oils are less selective than water-soluble contact herbicides, because the latter provide better differential wetting of weed foliage. Paraquat controls a broad spectrum of weeds, but the results of paraquat applications are not always predictable. We have observed better results during the cool winter than the hot summer season in southern California. Cacodylic acid, DSMA, and MSMA are excellent grass killers which have been used widely in citrus orchards to control certain perennials, particularly johnsongrass, bermudagrass, and vaseygrass.

Translocated herbicides are systemic in nature. Applied to one plant part, the herbicide penetrates tissues and is translocated to other tissues and organs. Dalapon and 2,4-D are common examples of foliar-applied systemic herbicides which are absorbed by leaves and moved through plant tissues into roots and rhizomes. Such herbicides are most effective in killing regenerating perennials, and they have the added advantage of not requiring complete foliage coverage.

Citrus trees need not be directly tolerant to foliage applications of contact or foliar systemic herbicides since these chemicals can be selectively applied to weed growth with only minor spray drift or accidental wetting of tree foliage. Use of foliar herbicides results in some degree of soil contamination. The injury is most likely to result from herbicide uptake by roots from the soil. For example, when dalapon is applied to grass foliage in orchards it can become leached into soil, reaching a concentration of 1 to 2 ppm in the trees' root zones and causing leaf and fruit drop. Thus, with proper application, the only hazard in the use of herbicides in citrus orchards is through the soil. For this reason, testing herbicides for orchard use is really a matter of determining citrus resistance to soil applications, whether normal treatments to weeds are in the form of foliar sprays or direct soil applications.

Pre-emergence Herbicides.—Soil-active herbicides are chemicals that kill plants by absorption through their root systems. Some of these species, such as methylbromide, metham, and other fumigants, may have only a brief effect. Other soil-active herbicides, such as diuron, sima-

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zine, and bromacil, may remain effective in soil for months or even years. These herbicides with long residual action are particularly valuable in citrus orchards requiring extended weed control.

Some herbicides fall into more than one category or may be in intermediate categories. Monuron, for example, is primarily soil-active, but it also exerts contact action on sensitive weed species. Diuron and bromacil, besides having long-term residual effects in soil, exert foliar activity when formulated with the proper surfactant. MSMA and DSMA are intermediate between contact and translocated types, and 2,4-D, although primarily a foliar systemic herbicide, can become leached into soil and exert its action through plant root systems.

Most herbicide applications are made so that the major portion of the herbicide is placed on weed foliage or soil and not on tree foliage or fruit. In such programs, the effects on trees result from absorption by tree roots and transport to leaves. To understand the correct use of herbicides in orchards, there must also be knowledge of their action in soils and on trees. A review of the activity and fate of herbicides in citrus trees and soils is provided by Jordan, Day, and Russell (1969).

Herbicides and Soil Leaching.—Movement, activity, and persistence of soil-active herbicides affect their usefulness and selectivity in orchards. Herbicide movement in citrus soils is mainly with water. Leaching of herbicides is dependent on solubility, nature of the herbicide, soil properties, and amount of water movement. Within an herbicide family, leaching is related to water solubility. Therefore, monuron, with a solubility of 230 ppm, leaches more rapidly than diuron, whose solubility is 42 ppm. The difficulty in comparing leaching rates of herbicides from different families with similar water solubilities is due to different strengths of the bonds between herbicides and soil particles.

Organic matter and, to a lesser extent, mineral colloids, adsorb herbicides, maintaining an equilibrium concentration in the soil solution. Highly soluble, lightly adsorbed herbicides are more effective for control of deep-rooted weeds, especially in soils high in clay or organic matter. In sandy soils, however, herbicides with low water solubility are potentially less hazardous to the trees. In soils with low adsorptive capacity, frequent light or infrequent heavy chemical applications are often needed to maintain a toxic concentration near the soil surface, and rapid leaching of the compounds under these soil conditions may lead to excessive concentrations in tree root zones. Relatively insoluble or strongly-adsorbed herbicides are not rapidly leached and are more effective for controlling shallow-rooted weeds around deep-rooted trees. More water is required to leach simazine (with a water solubility of about 5 ppm) into the area of germinating weed seedlings than to leach monuron, diuron, or bromacil. Slow leaching of simazine sometimes allows weeds to germinate and grow before toxic concentrations reach seedling roots. Trifluralin, with its very low water solubility of less than 1 ppm, virtually does not leach into soil. Therefore, it must be incorporated mechanically into soil to be effective.

Herbicide Toxicity.—Toxicity of herbicides in orchards varies with the nature of the soil. A given dosage of most herbicides is more toxic in sandy soils or soils low in organic matter than in soils high in clay or organic matter. There are often interrelations among cation-exchange-capacity, organic matter, clay content, and herbicide in soil solution which, in turn, affect an herbicide's phytotoxicity to trees and weeds.

For any particular soil-active herbicide, the dosage required for a given initial toxicity increases with increased organic matter and clay content of the soil. Herbicide toxicity is dependent upon an equilibrium of the amount of herbicide in solution and the amount adsorbed on the soil constituents. Adsorption equilibria may either bind most of an herbicide, or permit most of it to be in solution, available to plant roots. The amount in solution decreases as adsorption increases, and the degree of partitioning between solid and liquid phases is a characteristic peculiar to each soil-herbicide combination. This characteristic governs the rate of leaching, availability of the herbicide for adsorption by organisms and plant roots, and, in turn, the amount required to kill weeds or injure trees.

Persistence of herbicides in the soil varies considerably in different orchards, though this is not usually noted because dosages are adjusted to achieve the desired length of residual action in the soil. Soil classification based on particle size does not give a reliable index of an herbicide's true persistence. Soil-active herbicides are degraded by micro-organisms, and this decomposition, while somewhat related to soil properties, is predominantly regulated by the presence of two factors: organisms capable of metabolizing the herbicide, and conditions favorable for growth of

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the organisms. Thus, persistence is often related more to the soil's biological and environmental characteristics than to its physical and chemical characteristics.

Citrus tolerance to soil-active phenylurea, triazine, and substituted uracil herbicides is relative and not complete; therefore, overdoses of these herbicides will severely injure or kill trees. Although the mechanism by which herbicides injure citrus trees probably does not differ from the mechanism of action in other plants, relatively little research has been done to indicate why citrus is tolerant to herbicides at rates which would kill most other orchard trees. Injury symptoms progress through characteristic leaf chlorosis, necrosis of leaf tissue, abscission of leaves, twig and stem dieback, and finally death of the tree. Under field conditions, the injury symptoms are often difficult to distinguish from abnormalities arising from other causes.

Observations of the occurrence of leaf symptoms in citrus trees treated with overdoses of monuron, diuron, simazine, and bromacil indicate uptake and translocation throughout the tree. Analysis of leaves by chemical residue analysis reveals residues of the parent herbicide in the leaves (Jordan, Day, and Jolliffe, 1969). We have recently developed information (unpublished) indicating that phenylurea chloro-*s*-triazine and substituted uracil herbicides are metabolized to nontoxic chemicals by citrus seedlings.

Even though monuron, diuron, simazine, and bromacil residues are detectable in citrus leaves, insignificant or no residues are found in fruit from soil applications (Jordan, Day, and Jolliffe, 1969). Excessive residues of these herbicides in fruit are not likely unless they are sprayed directly on the fruit.

WEED-CONTROL PROGRAMS

Effective weed-control programs utilize all applicable methods. The best combination of methods varies from orchard to orchard, depending upon weed flora, soil and climatic conditions, and the degree of weed control desired. Where suitable, soil-active herbicides form the basic treatment of an overall control program and are used to control weeds originating from seed. Contact or translocated herbicides are usually necessary as supplemental treatments to control resistant annuals and established perennials. Cultivation and mowing are employed in areas where herbicides either cannot or should not be used over the entire orchard. Because of various environmental conditions, control methods differ in various citrus production regions of the world. This may be best illustrated by discussing weed-control programs in citrus-producing states in both the United States and other selected citrus-producing countries.

California

Orchard weed-control programs based entirely on contact spraying have been carried out for many years in California, although this method is no longer in widespread use. Under this procedure, the orchard soil is shaped in final form to facilitate irrigation and other orchard operations, and successive crops of weeds are sprayed soon after emergence and before the earliest-maturing species produce seed. The objectives are to prevent seeding of all species, kill perennials through exhaustion of food reserves, and ultimately exhaust seed supply near the soil surface. As spraying continues, the population of weed seeds close enough to the soil surface to germinate is depleted. Often by the third year, general spraying can be discontinued, and the occasional weed that appears can be eliminated by spot spraying, hoeing, or hand pulling. The success of the program is dependent to some extent upon controlling adjacent seed sources such as roadsides, fence rows, ditch banks, and nearby crop land. Once the program is established, however, the grower must entirely abandon cultivation as a soil-management procedure because a large population of buried seeds remain viable in soil for many years. Cultivation returns these to the surface where conditions are more favorable for germination, and the effects of previous sprayings are largely lost. Weed control by contact sprays is more expensive initially than maintenance cultivation, but it results in lower long-term weed-control costs (Lombard, 1944).

Weed-control programs based on contact sprays have the double advantage that they are not soil- or climate-dependent and are applicable to essentially all California citrus-growing districts. However, spraying is now largely limited to areas where both exceptionally light sandy soils with low adsorptive herbicide capacity and frequent irrigation cause soil treatments with residual herbicides to be both potentially more hazardous to trees and simultaneously limited in their effectiveness against weeds.

Use of soil-residual herbicides in citrus culture is a relatively recent development whose widespread use began with the introduction of

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monuron for groves in California in 1955 (Day, 1955). Since then, soil-active herbicides have become the most widely used group in citrus culture. In practice, soil-residual herbicides are sprayed on soil after the orchard is cultivated to final form and before weeds emerge. Rainfall or sprinkler irrigation is required to carry the herbicide into the zone where weed seeds germinate. The dosage required to kill weeds is lowest when weeds are young and increases as plants grow older. Usually 2 to 4 pounds per acre of monuron, simazine, diuron, bromacil, or terbacil are sufficient to control susceptible annual weed species in irrigated arid soils.

Bromacil and terbacil have been used in California for bermudagrass control at the rate of 4 to 6 pounds per acre, with applications being made to either foliage or soil. Bermudagrass is not usually eradicated with just one application, but requires spot treatments during the program's second year. After established grass is removed, the orchard can be put on a program similar to that for annual weed control. Seedlings must be controlled for several years to prevent re-establishment of bermudagrass sod. Bromacil and terbacil also show promise for nutsedge control, especially if proper timing and possible retreatment schedules are developed.

With the exception of control based on herbicide oils, weed control based on the use of a single herbicide has not been successful. The substituted urea, symmetrical triazine, and substituted uracil herbicides control a broad spectrum of weed species, but resistant species do exist. These are often rare and inconspicuous in orchard flora when treatment is initiated and also later when weed control is judged to be complete. However, even if certain euphorbias, composites, and a variety of perennials are not initially present, they thrive free of competition and ultimately infest the entire orchard once they are introduced. This often can be prevented by alternation between available soil-residual herbicides. Spotted spurge is resistant to all three classes of soil-residual herbicides and must be controlled with occasional spot treatments with petroleum oil. Some grass species are resistant to simazine, especially during summer. With normal vigilance and proper combinations of treatments, reinvasion by resistant species is rarely serious. Combinations of herbicides, e.g. diuron and bromacil, will often control weed species which escape either herbicide alone.

Translocated systemic herbicides may be used to control annual weeds in spot infestations of perennial weeds. Most foliar-active systemic herbicides are too toxic to trees to permit their orchard-wide use at rates required to control perennial weeds. An exception is 2,4-D, which is effective for suppressing field bindweed and other susceptible species at rates up to one pound per acre, but direct spraying or excessive drift to trees must be avoided.

Arizona

According to Hamilton,[4] the most common weed-control program in Arizona's bearing citrus orchards is six to eight mechanical cultivations with disks or rotary plows each year, with irrigation borders or ridges reshaped after each cultivation. Less than 15 per cent of bearing orchards are treated with soil-applied herbicides. Simazine and diuron are applied to soil once or twice each year before irrigation or rainfall to control annual weeds, but some growers will not use diuron because it often causes foliage chlorosis in May and June. Applications of simazine or diuron are sometimes followed by spot applications of weed oil to foliage of weeds that escape or survive soil-applied herbicides. Infestations of perennial weeds are spot-treated with weed oils, paraquat, or MSMA.

In young, nonbearing citrus orchards, weeds are usually controlled by limiting irrigation to a narrow basin between two ridges of soil. Weeds emerging after each irrigation are usually controlled with foliar applications of weed oil or paraquat. Weeds in nonirrigated areas are disked as needed. As the citrus matures, the narrow irrigation basins are replaced by single ridges of soil between tree rows.

Florida

According to Ryan (1969), noncultivation as practiced in arid to semiarid California (120 to 800 mm of annual rainfall) has not been considered a feasible approach to weed-control problems in most groves in the more humid climate of Florida (2,000 to 2,400 mm of annual rainfall). Much of the citrus is grown on a central "Ridge" area on excessively drained deep fine sand or fine sandy loam, and much of it is on rolling low hills where bare soil in a young grove would permit both water and wind erosion and tree damage from blowing sand. In imperfectly drained areas where citrus is grown on shaped raised beds,

[4] Personal communication from K. C. Hamilton, University of Arizona, Tucson.

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some vegetation on slopes is required to prevent bed erosion.

Periodic disking, chopping, or mowing are commonly used for weed control in row middles, but research in Florida has been directed primarily at the use of herbicides in the root zone around the trunk of young trees. There may be, in addition, some localized areas and grove conditions where complete weed control with herbicides is desirable.

Since 1964, herbicides have been used on many acres of young citrus in the Ridge area and more recently on coastal and flatwoods areas. Seasonal control of most annual weeds is achieved with diuron and simazine, but at rates usually higher than those used in California. Weed control is generally more satisfactory with diuron even when compared to higher rates of simazine. Both chemicals require rainfall or irrigation following application for satisfactory results, yet simazine appears to be more adversely affected than diuron by inadequate moisture. As a result, diuron is more widely accepted for control of annual weeds around young trees in the relatively uniform soil of the Ridge area.

Careful use of herbicides is very important in Florida's coastal and flatwoods areas, where soils are often imperfectly drained. The soil type is more variable initially and the profile is usually disturbed during leveling of the land and preparation of raised beds and ditches before planting. The surface soil within a single grove may vary from light-colored sand with very little organic matter to much finer textured soil and soil with relatively high organic matter content. It is difficult to select an herbicide rate that provides good weed control without some tree injury in such soils (Kretchman, 1962; Ryan and Kretchman, 1962).

The occurrence of perennial grasses in coastal and flatwoods areas limits the use of monuron and diuron. Prior to 1967, dalapon was recommended for controlling patches of paragrass and guineagrass, but it is not suggested for use on trees younger than four years old because of the possibility of tree injury. Control of these grasses has been erratic due to several possible factors.

According to Phillips and Tucker,[6] bromacil is widely used in the industry at rates of 3 to 4 pounds per acre twice a year to control perennial grasses. Where spanishneedles and pigweed are problems, a combination of bromacil and diuron is recommended. Bromacil may also be used for the preplanting eradication of torpedograss at the rate of 24 pounds per acre, with spot applications at four- to six-month intervals to kill any surviving grass (Kretchman, 1962). Trees may then be planted one year after the initial treatment. Terbacil has been used for perennial grass control with less indication of toxicity to young trees (Ryan, 1966). Terbacil applied two or three times a year will control perennial grasses in groves at least one year old and, in addition, it controls most annual weeds as effectively as does bromacil.

Contact herbicides are utilized in Florida during the first year after planting to replace hand hoeing. Paraquat is applied three to four times per season with the rate adjusted according to weed stand. Injury may occur if the herbicide comes into contact with green tissue, but bark is not injured with normal herbicide applications.

Vines are a major problem in Florida citrus groves (Phillips, 1970; Ryan, 1966). Without the use of herbicides, considerable hand labor is required to control Virginia creeper, milkweed, balsamapple, and moonflower vines. The annuals may be controlled by the timely use of a number of pre-emergence herbicides. Perennial species such as milkweed vine are controlled by dichlobenil incorporated into soil, and Virginia creeper is controlled experimentally by silvex applied to vines under the trees.

Texas

Conventional tillage in Texas orchards requires six to eight diskings a year, one in conjunction with each irrigation and an additional fall cleanup before cold weather (Leyden, 1969). Some weeds are able to mature and set seed in the interval between diskings; this is particularly true of careless weed. Damage to tree trunks and branches which often occurs under cultivation may result in infestation by insects and diseases.

Year-round weed control is recommended, and control of weeds both in and between rows is strongly desired. The herbicide should be effective against a broad spectrum of weed species and provide long residual control. Often specialized herbicides that are effective against problem weeds are required.

In 1971, chemical weed control was being used on about 40 per cent of citrus acreage in

[6] Personal communication from R. L. Phillips and D. P. H. Tucker, Florida Citrus Experiment Station, Lake Alfred, Florida.

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Texas.[a] Herbicide recommendations for Texas orchards include use of the pre-emergent herbicides diuron, bromacil, terbacil, simazine, and trifluralin for control of annual broadleaf species and grasses. Bromacil and terbacil are also used for control of nutsedge and established grasses.

Most weed species are controlled with the aforementioned herbicides, although some established weeds may still survive, requiring spot treatment with contact herbicides. Paraquat and petroleum weed oil are effective for control of this unwanted vegetation, although petroleum weed oil is used less extensively than paraquat. Johnsongrass, bermudagrass, and other established grasses are controlled with dalapon. Weeds that have been particular problems in chemical weed-control orchards the past few years are purslane, guineagrass, silverleaf nightshade, and vines.

Australia

Turpin *et al.* (1970), reported rapid adoption of herbicides in New South Wales as an alternative to cultivation. Diuron, bromacil, and simazine are recommended for use in established groves for residual control of germinating weeds. Paraquat and bromacil with an added surfactant are useful for controlling emerged annuals or for spot-treating perennials.

The combination of an overall spring herbicide treatment with a winter legume cover crop is promising to become the standard weed-control practice. Subterranean clover and early maturing medics are used for cover crops to prevent erosion during the winter rainy season. The cover crops prevent much normal weed growth without cultivation. Herbicide treatment in the spring removes the vegetation until fall when the legumes become re-established. The practice is not appropriate in colder orchards because cover cropped areas are colder than bare soil orchards and enhance frost damage.

Israel

Goren and Monselise (1969) report that bermudagrass is the most troublesome weed in young citrus orchards in Israel. The triazine and substituted urea herbicides were effective only in controlling annual weeds but not bermudagrass. The use of bromacil has solved the bermudagrass problem, and combinations of bromacil with simazine and fluometron extend weed control to some species not controlled by bromacil alone.

Italy

Torrisi (1969) reports that in Sicily herbicides are becoming widely applied in commercial orchards. Monuron, diuron, simazine, and bromacil are the soil-active residual herbicides used. Monuron controls most annual weeds with semi-annual applications, one in fall and a second in spring. Diuron is employed in very light, sandy soils where monuron is not recommended because of excessive leaching and potential toxicity to trees. Simazine alone or in combination with atrazine or amitrole has been used only on a limited scale because of its failure to control widespread foxtail during summer in a majority of orchards. Bromacil has been effective for control of purple nutsedge and bermudagrass, as well as several annual weed species.

Low volatile esters of 2,4-D and 2,4,5-T are used to control some broadleaf weeds which escape soil-residual herbicides. These include Bermuda buttercup and field bindweed. Dalapon has been used for bermudagrass, but is being replaced by bromacil. Repeated treatments of 2,4-D, 2,4,5-T, and dalapon are required for perennial weed control.

Japan

Oohata (1969) states that the high precipitation and steep slopes common in most Japanese citrus orchards require a ground cover to protect soils from erosion. A contact herbicide is often used in April to control vegetation until June, when the rains begin, and herbicides are applied once after the rainy season to prevent competition for moisture during the dry season. The second treatment is made in late July when weeds are large and mature and a good contact herbicide is required to kill them. Selectivity is desired to prevent injury from accidental spray drift to citrus foliage. Paraquat is widely used, although it will injure green tissue of citrus upon contact, but wydac is rapid acting and causes no tree damage at rates employed.

The addition of the proper surfactant often provides the desired contact activity. Bromacil with surfactant is the preferred soil residual herbicide.

South Africa

Herholdt (1969) described the diverse weed-control problems and programs in South Africa. Weed-control methods in 1967 were listed

[a] Personal communication from Arlen D. Klosterboer, Assistant Professor, Texas A & M University Citrus Center, Weslaco, Texas.

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in declining magnitude as follows: cultivation, hand hoeing, chemical weed control, cover crops, and mulching. Combinations of different methods are often used. Cover crops are grown in the rainy seasons with cultivation or herbicide treatments for weed control during the dry season. Cultivation was practiced on about 75 per cent of the acreage in 1967, but Herholdt (1969) believes that despite cheap hand labor, 80 per cent of the acreage could be economically treated with herbicides, eliminating many of the disadvantages of mechanical cultivation and hand hoeing. The conversion to chemical weed control with herbicides such as simazine, diuron, bromacil, and paraquat is expected during the next decade.

BENEFITS FROM WEED-CONTROL PROGRAMS

Orchards maintained weed-free, especially in tree rows, often have more vigorous trees which produce higher fruit yields (Goren and Monselise, 1969; Herholdt, 1969; Jackson, 1970; Leyden, 1969; E. C. Moore, 1944, 1945; P. W. Moore, 1944; Ryan, 1969; Turpin *et al.*, 1970). Leyden (1969) illustrated the benefits of chemical weed control in Texas, and his data is shown in table 3–4. Growth, indicated by trunk diameter, was significantly greater with chemical weed control than with clean cultivation or sod culture. Yield was higher on larger trees because of greater bearing surfaces.

Others have reported no difference in yields from trees where chemical and cultural controls were used (Lombard, 1951). Comparison of trees treated with different herbicides reveals that growth and yield are greater as efficiency of weed control increases (Jackson, 1970; Ryan, 1969; Ryan and Kretchman, 1968). Growth and yield are both decreased by severe tree damage from herbicides, and directly affected by the amount of competition between weeds and trees. As competition increases, potential tree growth and yield decrease, and the necessity for weed control becomes more urgent and the results more beneficial.

Table 3–4
INFLUENCE OF CULTURAL SYSTEM ON GROWTH AND YIELD OF REDBLUSH GRAPEFRUIT ON SOUR ORANGE ROOTSTOCK AS ESTIMATED BY TRUNK DIAMETER MEASUREMENTS*

Cultural System	Trunk Diameter (Cm)			Yield (Kilos Per Tree)	
	1964	1965	1966	1966	1967
Chemical Weed Control With No Tillage	8.70$_a$†	13.60$_a$	18.20$_a$	95	107
Clean Cultivation	6.00$_b$	10.40$_b$	15.50$_b$	10	74
Sod Culture	4.95$_b$	7.70$_b$	12.10$_c$	4	13

Source: Adapted from Leyden (1969).

* Trees planted summer, 1960, subjected to severe freeze, January, 1962.

† Values followed by different subscripts differ significantly at the 5 per cent level, Duncan's Multiple Range Test.

There is little published information concerning effects of weeds and their control of fruit quality. One report indicates that puffing, creasing, and fruit drop are problems arising in some varieties from intensive noncultivation (Torrisi, 1969). Most reports indicate no definite conclusions concerning the effect of weed control methods on fruit quality (Jordan, Day, and Russell, 1969; McCarty, Day, and Russell, 1960; Ryan, 1969). Jackson (1970) reports an increase in fruit quality as well as yield.

The effect of weed-control methods on orchard soils has received some attention. Continuous cultivation results in formation of a compacted layer of soil (plow sole) in some orchards which impedes water penetration (Kimball *et al.*, 1950; Lombard, 1944; E. C. Moore, 1944; P. W. Moore, 1944, 1946; Rutherford, 1944*a*; Yarrick, 1946). Water penetration is increased when orchards are changed from cultivation to noncultivation with herbicides because the plow sole is broken down (Lombard, 1944; E. C. Moore, 1944, 1945; P. W. Moore, 1946; Rutherford, 1944*b*).

Some soils form an impervious crust when on noncultivation with herbicides. Water penetration is reduced in comparsion to cover-cropped or cultivated soils (Werenfels *et al.*, 1963). Shallow cultivations alleviate the problem and, as leaf mulch from trees builds up, crusting becomes less severe.

Cultivation prunes tree roots growing in the layer of disturbed soil. Conversion to noncultivation with herbicides allows tree roots to grow in the surface layer of soil (Jordan, Day, and Russell, 1969). Kimble *et al.* (1950) reported that, under noncultivation, 71 per cent of feeder roots were in the upper two feet of soil compared to 50 per cent in cultivated soil.

Conversion to noncultivation decreases root and trunk damage from equipment and invading diseases, eliminates weed competition,

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and results in more vigorous trees which recover more rapidly from stress conditions (Jackson, 1970; E. C. Moore, 1944, 1945; P. W. Moore, 1944). The beneficial effects of reduced root pruning is more pronounced in shallow soils where feeder roots are closer to the surface than in deep soils where tree roots penetrate deeper into the profile.

Soil and air temperatures are higher in orchards with bare soil (Leyden and Rohrbaugh, 1963; Ryan, 1966; Ryan and Kretchman, 1962). Leyden reported that orchards were 2 to 3 degrees warmer in plots under chemical weed control than in adjoining plots under clean cultivation or sod culture where vegetation was present (Leyden and Rohrbaugh, 1963; Leyden, 1964, 1965, 1969). After a freeze, trees under chemical noncultivation had the least frost-injured wood, while trees under sod culture had the most (see chap. 10). Recovery and growth during the years following the cold injury was more rapid in the herbicide-treated orchards (Leyden and Rohrbaugh, 1963).

PRECAUTIONS IN THE USE OF HERBICIDES

Even though most herbicides in common use have low toxicity to man and animals, they vary enough in toxicity to demand extreme caution in their use. Careless use of herbicides may result in injury to anyone coming into contact with the crop: the applier, people working in the fields, and even consumers. In addition, misuse of herbicides may endanger other desirable plants and wildlife. The following list of precautions should always be followed in using herbicides:

1. Anyone recommending use of an herbicide should be thoroughly familiar with precautions necessary for its safe use. He must also convey this information to the applier.*

2. Before applying an herbicide, the user must read all precautionary labeling directions, following them exactly so that only proper amounts of herbicide are applied in accordance with the methods of application and at the times specified on the label.

3. Herbicides must be kept out of reach of children, pets, livestock, and any irresponsible person. Sprays, dusts, and granules should be stored in original containers (which should be kept tightly closed).

4. Workers should avoid inhaling sprays and dust; this is most effectively accomplished by not working in the drift of the herbicide.

5. Protective clothing and proper face masks should be worn as directed on the herbicide label. If herbicides are accidentally spilled on either skin or clothing, the clothing should be removed immediately and the contaminated skin should be thoroughly washed. Clothing should be washed before reuse.

6. After applying herbicides, the applier should wash his hands and face, and change to clean clothing which has not been exposed to any herbicide. In addition, *any* person handling herbicides—either in the mixing or application stages—should not eat, chew, or smoke until washing his hands and face. Finally, the mouth should not be used to siphon liquids or to blow out clogged lines or nozzles.

7. If symptoms of illness occur during or after dusting or spraying, a physician should be consulted, or the patient taken to a hospital immediately.

8. Labeled directions and recommendations should be followed to maintain residues on edible portions of plants within the limits permitted by law.

9. All food and water containers near treatment areas should be covered during application of herbicides.

10. Care should be taken not to contaminate fish ponds, streams, or lakes.

11. Leftover materials should not be disposed of in drainage channels or irrigation ditches.

12. Empty herbicide containers should be disposed of in a manner so that they pose no hazard to humans, animals, valuable plants, or wildlife.

13. Herbicides should be confined to the property being treated. This can be accomplished by avoiding drift in the air, not moving contaminated soil, and not allowing herbicides to erode into adjacent areas if concentrations are high enough to cause damage to susceptible crops or animals.

14. The applier must be familiar with local laws governing the use of herbicides. Most countries and political subdivisions have legislation aimed at decreasing risks from the unwise use of herbicides. Since these regulations are quite variable, careful attention must be paid to the penalties and liabilities which arise from both proper and improper use of herbicides.

15. It is important to thoroughly research

* In California he must be licensed.

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new herbicides to determine whether the benefits from their use will be greater than their potential harmful effects. New formulations of herbicides are constantly being introduced on the market, and it is unfortunate that their sale is often promoted before adequate information is available concerning their safety under local agricultural conditions for man, animals, or crops.

Herbicides are periodically removed from the market or their use is discontinued because new information is derived indicating that the herbicide is harmful, that it does not perform the beneficial function for which it was intended, or because it can be replaced by a more desirable method of weed control. Because the use of herbicides is a dynamic science, and the role of individual herbicides in weed-control programs is always changing, the mention of the use of an herbicide in literature for a particular use may not represent the best current information or guarantee that its use is legal according to local legislation. Therefore, one should always consult with local authorities concerning the advisability and legality of using any particular herbicide.

LITERATURE CITED

ANONYMOUS. 1964. Report by the statewide weed control committee of the California state chamber of commerce. 39 pp.

ANONYMOUS. 1965. Losses in agriculture. U. S. Dept. Agr., Agr. Handbook No. 291:82pp.

DAY, B. E. 1955. Urea herbicides for citrus weed control. Calif. Citrog. 40:398, 408, 410–12, 414.

DAY, B. E., and L. S. JORDAN. 1967. Noncultivation weed control in citrus. Proc. XVIIth Intern. Hort. Cong. 3:137–43.

——— 1969. A research program for adaptation of herbicides to citrus culture. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. 1:459–62. Univ. of Calif., Riverside, Calif.

GOREN, R., and S. P. MONSELISE. 1969. Studies on the utilization of herbicides in citrus orchards in Israel as related to efficiency. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. 1:483–92. Univ. of Calif., Riverside, Calif.

HERHOLDT, J. A. 1969. Weed control in South African citrus orchards. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. 1:499–502. Univ. of Calif., Riverside, Calif.

JACKSON, L. K. 1970. The death of the plow. Herbicides—the total picture. Citrus. Indus. 51(12):24, 27.

JOHNSTON, J. C., and W. SULLIVAN. 1949. Eliminating tillage in citrus soil management. Calif. Agr. Ext. Serv. Circ. No. 150.

JORDAN, L. S., B. E. DAY, and V. A. JOLLIFFE. 1969. Residue of herbicides and plant growth regulators in citrus. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. 2:1063–69. Univ. of Calif., Riverside, Calif.

JORDAN, L. S., B. E. DAY, and R. C. RUSSELL. 1969. Herbicides in citrus trees and soils. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. 1:463–66. Univ. of Calif., Riverside, Calif.

KIMBALL, M. H., A. WALLACE, and R. T. MUELLER. 1950. Changes in soil and citrus root characteristics with non-tillage. Calif. Citrog. 35:409, 432–33.

KRETCHMAN, D. W. 1962. Torpedograss and citrus groves. Univ. Fla. Expt. Sta. Circ. S-136.

LEYDEN, R. F. 1964. Chemical weed control with no tillage: a cultural practice for Texas citrus orchards. Jour. Rio Grande Val. Hort. Soc. 18:25–28.

——— 1965. Lower costs, warmer groves, chemical weed control. Citrus Veg. Mag. Fla. Farmer. 28 (4):34–35.

——— 1969. Development of the herbicide program in Texas. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. 1:473–77. Univ. of Calif., Riverside, Calif.

LEYDEN, R. F., and P. W. ROHRBAUGH. 1963. Protection of citrus trees from cold damage. Proc. Amer. Soc. Hort. Sci. 83:344–51.

LOMBARD, T. A. 1944. Oil weed control—cultivation vs. non-cultivation. Calif. Citrog. 29:212.

——— 1951. Does non-tillage increase Valencia orange yields? Calif. Citrog. 36:182.

MCCARTY, C. D., B. E. DAY, and R. C. RUSSELL. 1960. Effect of monuron on lemon fruit quality. Calif. Citrog. 45:174.

MOORE, E. C. 1944. Nontillage weed control by oil spray. Calif. Citrog. 30:53.

——— 1945. Nontillage weed spray program in Tulare County. Calif. Citrog. 30:289–91.

MOORE, P. W. 1944. Oil sprays for weed control in untilled citrus orchards. Calif Citrog. 29:246, 251.

——— 1946. Grass roots view on non-cultivation. Calif. Citrog. 31:200, 218.

OOHATA, J. T. 1969. Herbicides in Japanese citrus growing. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. 1:493–97. Univ. of Calif., Riverside, Calif.

PHILLIPS, R. L. 1970. Vine control in citrus groves. Citrus Indus. 51(1):4–5.

REUTHER, W. 1969. Premature fruit drop. Mimeo rept. Univ. West Indies, St. Augustine, Trinidad. 9 pp.

RUTHERFORD, D. M. 1944*a*. Mr. Johnson's infamous grass. Calif. Citrog. 29:310.

——— 1944*b*. Water and weed control. Calif. Citrog. 29:200–01.

RYAN, G. F. 1966. Evaluation of substituted uracil herbicides for use in citrus. Proc. Fla. State Hort. Soc. 79:30–36.

——— 1969. The use of chemicals for weed control in Florida citrus. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. 1:467–72. Univ. of Calif., Riverside, Calif.

RYAN, G. F., and D. W. KRETCHMAN. 1962. Chemical and weed control in bedded groves. Citrus Indus. 43 (12):25.

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——— 1968. Effects of four herbicides on growth and yield of orange trees. Proc. Amer. Soc. Hort. Sci. 93:159–65.

Torrisi, S. 1969. Development and use of herbicides in Sicilian citrus orchards as a means for nontillage weed control. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. 1:479–82. Univ. of Calif., Riverside, Calif.

Turpin, J. W., J. B. Forsyth, J. E. Cox, and R. D. Mackay. 1970. Herbicide management in citrus orchards. Agr. Gaz. N. S. Wales. 81(2):50–58.

Werenfels, L., E. L. Proebsting, R. M. Warner, and R. Tate. 1963. Cover crops improve infiltration rates. Calif. Agr. 17(5):4–5.

Yarrick, B. E. 1946. Notes on non-tillage. Calif. Citrog. 31:318–20.

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CHAPTER 4

Soils, Soil Management, and Cover Crops[1]

WINSTON W. JONES and TOM W. EMBLETON

CITRUS IS GROWN IN SOILS ranging from sands to clays while cover crops are grown in winter, summer, or both winter and summer as permanent sod. Sometimes no cover crops are grown, the orchard is kept free of all growth by chemicals, and no tillage is performed. The fact that citrus is grown on a specific soil type or that a particular cultural practice is carried out does not mean that these are necessarily the ideal operations. Many cultural practices appear to be based on tradition rather than on known principles established by experimental data. Many problems encountered in citrus production are caused by planting on soils not suited to tree growth or by cultural practices that were continued beyond the point of being beneficial.

In considering soils for production of a tree crop such as citrus, it must be remembered that trees may become deeply rooted. Roots have been found under citrus trees to a depth of 19 feet, extending to a distance of 25 feet from the trunk (Ford, 1954*a*). Thus, not only must the characteristics of the surface soil be considered but also those of the deep subsoil. Many soil-management practices affect only the surface layer of soil, but these practices are of extreme importance since both water and air must pass through the surface layer to the lower depths.

In this chapter, we discuss some of the limiting factors of soils and the advantages and disadvantages of cover crops and various cultural practices.

SOILS

Soil is not essential for the growth of citrus trees (Chapman, Brown, and Rayner, 1947). All that is needed are physical support and the essential elements, including oxygen and water. Under field conditions, however, soil is the medium through which the essential elements are supplied. The ability of a given soil to supply these materials depends on both its physical and chemical characteristics.

Physical Characteristics of Soils

Attention has been directed to the importance of the physical nature of soils as affecting aeration and the depth of rooting. The physical characteristics are determined by the size distribution of the soil particles (texture), the positional relation of these unit particles to one another (structure) in the various soil strata or horizons, and the relations of the strata to one another (profile characteristics). These factors determine the total pore space and the size of the pore spaces through which water and air must move in the soil.

Water Infiltration.—The ability of a soil to permit water infiltration is one of its critical characteristics. Infiltration is determined in part by soil texture. In general, water moves into a sandy soil more rapidly than into a clay soil; however, particle size is not the only factor controlling infiltration. Small particles may be aggregated into water-stable particles of larger size, which greatly increases infiltration. On the other

[1] This chapter expands on material presented originally in Edwin R. Parker's chapter (chap. 4) in the first edition (vol. II) of *The Citrus Industry* (Batchelor and Webber, 1948). That information is combined with other data covered in the chapters by Warren R. Schoonover and Leon D. Batchelor (chap. 6) and Leon D. Batchelor (chap. 7).

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hand, particles of any size, may be cemented together to form impermeable layers. If such layers occur at the soil surface, they are called crusts; if they occur at various depths in the soil, they are called hardpan. Hardpan may be a natural characteristic of the soil profile or induced by tillage operations, in which case it is then called plowpan. Such impermeable layers retard infiltration, drainage, and aeration, and should be corrected or avoided.

Soil Drainage and Depth.—No single characteristic of good citrus soil is more essential than good drainage. Without satisfactory drainage, accumulation of free water in the root zone results in poor aeration and injury to roots. In regions of heavy rainfall, the use of shallow soils with impervious subsoils is particularly hazardous because under such conditions, the roots may be more susceptible to infection. Lack of drainage results in an accumulation of salinity, which, in turn, may reduce yields (fig. 4–1). Under irrigation, if the salinity of irrigation water increases, it is necessary to pass more water through the root zone to carry away salts fast enough to maintain salt concentrations in the soil solution low enough for good yields (Eaton, 1958). Thus, any restriction of drainage becomes especially harmful where irrigation is practiced.

Intermediate areas do exist, such as those near the coasts and in the low-lying, nearly level, poorly-drained areas of Florida, where good orchards grow above water tables that fluctuate between two and five feet below the surface. In such areas, special drainage and irrigation procedures are necessary (Reitz and Long, 1955; Young, 1953; Sites *et al.*, 1961*a*). More nearly constant-level water tables are less harmful than fluctuating water tables. Roots developing in the lower depths during periods of low water table are killed when the water table rises. In general, good orchards are rarely found growing on less than three feet of well-drained soil. Less well-drained conditions are hazardous, since successful growth requires rapid lateral movement of water in the soil to a nearby point of removal or fractures in the subsoil permitting drainage. Chronic water damage is a common cause of substandard yields. Thus, carefully controlled cultural practices are advisable for shallow soils, and the installation of drainage ditches or tile drains along with irrigation facilities may be necessary. Iron oxide deposits in tile drains may be a problem in some areas (Ford and Spencer, 1962; Spencer, Patrick, and Ford, 1963). Low areas, where water accumulates as a result of surface or subsurface drainage, and where the accumulation cannot be removed in 48 to 72 hours, are usually unsuited to citrus production either because uncontrollably high water tables develop periodically or salts accumulate.

In residual soils, the soil depth satisfactory for the growth of citrus roots may be limited by the presence of the parent rock from which the soil was formed. In old alluvial and similar soils, the presence of a cemented stratum or a tight clay layer may have the same effect. Such shallow soils should not be planted to citrus unless thorough examination indicates that the problem can be handled. Areas where the limiting material is not decomposed or fissured to such a degree as to permit adequate water movement should not be used, although occasionally, hardpan or tight clay layers may be thin enough to permit partial destruction by ripping with heavy subsoil tools.

Since the effects of persistent free water within the root zone are so serious, the possible existence or formation of a water table should be studied even where a definite slope exists and

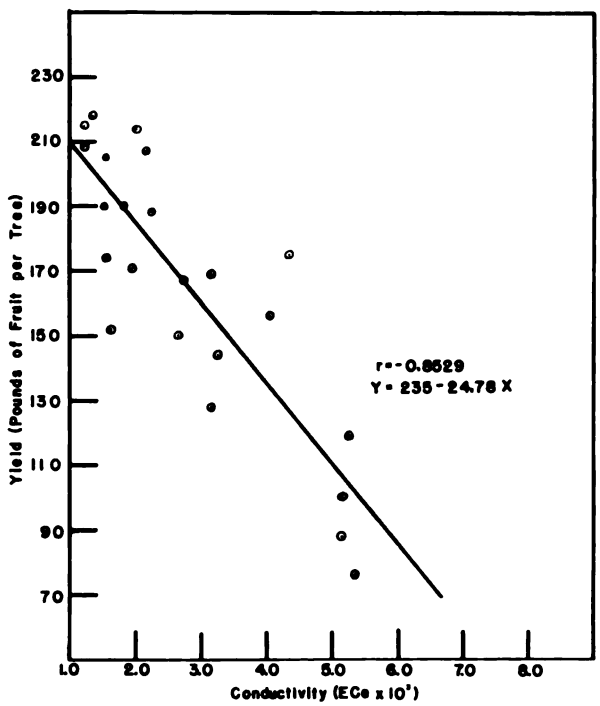

Fig. 4–1. Relationship between average conductivity of soil to a depth of 48 inches and average yield of orange fruits, 1951–56. Salinity is expressed in conductivity units of the saturation extract. (From Harding, Pratt, and Jones, 1958.)

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Table 4–1
EFFECT OF DEPTH ON COMPOSITION OF ROOTLETS OF VALENCIA ORANGE TREES ON ROUGH LEMON STOCK

Fertilizer Treatment*	Depth of Rootlets in Soil in Inches	Concentration in Dry Matter†						
		N (Per Cent)	P (Per Cent)	K (Per Cent)	Ca (Per Cent)	Mg (Per Cent)	Cu (Ppm)	Zn (Ppm)
$N_1K_1Mg_1$	0–10	1.22	0.20	0.46	0.37	0.64	241	1,810
	11–30	0.89	0.14	1.05	0.22	0.41	59	585
	31–60	0.80	0.14	0.94	0.16	0.32	16	161
	61–108	1.06	0.20	0.81	0.15	0.44	29	369
$N_3K_1Mg_1$	0–10	1.46	0.15	0.37	0.34	0.47	296	2,448
	11–30	0.97	0.09	0.61	0.19	0.41	112	1,545
	31–60	1.15	0.10	0.73	0.13	0.25	37	472
	61–108	0.97	0.13	0.54	0.20	0.47	75	257
$N_3K_3Mg_1$	0–10	2.02	0.18	2.20	0.66	0.41	250	2,108
	11–30	1.42	0.12	2.93	0.32	0.19	66	508
	31–60	1.25	0.10	3.15	0.22	0.11	30	255
	61–108	1.32	0.11	3.51	0.20	0.13	61	191
$N_3K_3Mg_3$	0–10	1.55	0.16	2.06	0.39	0.44	248	1,721
	11–30	1.12	0.09	2.46	0.24	0.29	80	648
	31–60	1.14	0.09	3.34	0.19	0.15	81	408
	61–108	1.43	0.12	5.05	0.20	0.26	32	675

Source: Reuther *et al.* (1958).

* The symbols N_1, K_1 and Mg_1 indicate low levels of nitrogen, potassium, and magnesium fertilization, and N_3, K_3, and Mg_3 indicate high levels.

† Corrected to SiO_2-free basis by deducting weight of acid-insoluble ash from dry weight of sample. Each value is the mean of four determinations from each of four plots.

especially if a location is at about the same elevation as nearby bodies of water. Irrigation and drainage ditches that are not waterproofed sometimes create water tables in adjacent lands. If water tables are found, it may be possible to intercept the flow creating them or to lower them by drainage with open ditches or tile drainage, provided adequate outlets can be obtained. Perched water tables occasionally are formed when a fine soil overlies a very coarse-textured soil, if the line of contact between the two is sharply defined, or if clay lenses occur in a coarse-textured soil.

Soils possessing a rather uniform profile within the normal root zone are usually the most satisfactory for citrus tree performance, since water movement is not impeded by variations in texture. Root development is also more uniform in such soils. Uniformity of soil throughout the orchard greatly facilitates cultural operations, particularly fertilization and irrigation.

Between very sandy soils at one extreme and clay soils at the other, there are numerous soil types satisfactory for the production of citrus trees. In general, the deep, well-drained sandy loam soils are best for citrus production, but with careful adjustment of cultural practices to the type of soil, citrus can be grown satisfactorily on a wide range of soils.

Root Distribution.—As mentioned earlier, root systems under citrus trees may be extensive. The roots are seldom seen or even considered until some stress occurs in the tops of trees. In discussing root distribution under fruit trees, Reuther, Embleton, and Jones (1958) pointed out that the roots are more extensive and probe deeper into the subsoil than those of most annual crop plants. Citrus roots are functional through all four seasons and over a span of many years. Thus, the root system of a citrus tree is subject to a wide range or gradient in physical environment, mineral-nutrient availability, and temperature. In winter, roots in the subsoil are appreciably warmer than roots in the topsoil; in summer, the reverse is true (see chap. 9). Because the physical and chemical make-up of the soil usually varies markedly with depth, one portion of a tree's root system may be in a well-aerated topsoil and another in a poorly-aerated subsoil. Thus roots are subjected to a decreasing oxygen supply and to both direct and inverse mineral-nutrient gradients with increasing

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depth. Table 4–1 indicates that such a changing environment exerts a profound influence on the mineral composition of roots.

Rooting depth and the density of roots at a given depth are influenced by all of the factors discussed above. Hilgeman and Van Horn (1954) in Arizona and Cahoon, Morton, and Jones (1959, 1960) in California, found that most roots occur in the top three feet of soil. In Florida, Ford (1954*a*) found roots as deep as 17 feet, and, in some cases 62 per cent of feeder roots were below 30 inches. Oxygen tension might well be one of the controlling factors on root extension under these various conditions. At a low-oxygen concentration, Stolzy *et al.* (1961) and Letey *et al.* (1961) reported a complete stoppage of root growth.

The amount of feeder roots and the depth of the rooting zone may influence tree size (Ford, 1954*b*) and fruit production (Cahoon, Morton, and Jones, 1959). Figure 4–2 shows that yields may be reduced when soil conditions inhibit the growth of roots. Ford, Reuther, and Smith (1957) found no relation between root density and production, but observed that high levels of nitrogen did decrease root density. This fact will be discussed more fully in Chapter 5, but it should be noted that the overuse of an essential fertilizer element has a detrimental effect on the root system and continued over a long period of time can reduce the root system to the point of limiting yields.

Chemical Characteristics of Soils

Nutrient Deficiencies and Excesses.—The native fertility of citrus soils is less important than the physical characteristics. Fundamental differences in the fertility of soils used in citrus culture exist under different climatic conditions and those fertility differences are affected by previous land use. A soil of low fertility with good drainage and other physical characteristics is superior to a soil of high fertility with poor physical characteristics. Thus, in general, sandy and sandy loam soils of low fertility are preferable to clay and clay loam soils of high fertility for citrus culture.

Soil analysis for diagnosing the nutritional status of a tree has serious limitations. The most important of these is a lack of general correlation between tree behavior and soil composition. Titus and Boynton (1953) found such correlation in McIntosh apples to be far from perfect and "disappointing" from the nutritional diagnostic and prognostic viewpoint. The relationship between the chemical nature of the soil and the nutritional status of the tree is complex, since the nutritional status of the tree is influenced by several factors which have no bearing on the amount of nutrients in the soil. Such factors as variety, rootstock,

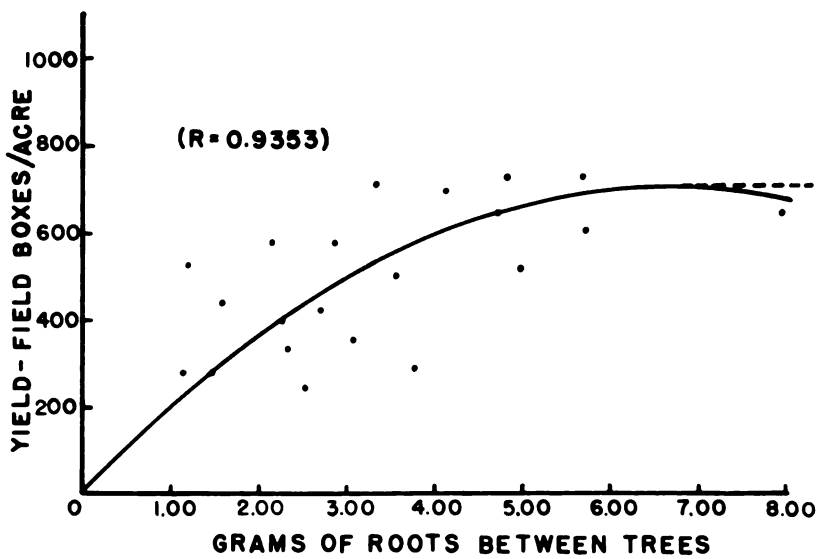

Fig. 4–2. Curvilinear relationship found when roots taken from sample holes (0 to 3 feet deep) between trees in 22 southern California orchards were compared with fruit yield. The regression coefficient (R = 0.9353) is significant at the 0.01 level of probability. (From Cahoon *et al.*, 1959).

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climate, soil temperature, soil moisture, nutrient interrelation, biological condition, and others all limit the usefulness of soil analysis. These limitations are more serious for tree-crops than for row crops. Roots of row crops absorb nutrients from a relatively restricted volume of soil of relatively uniform composition, which is easy to sample. Roots of tree crops penetrate to much greater depth than those of row crops and hence encounter an unusually-broad gradient in nutrient availability. With such conditions it is difficult to obtain a soil sample that adequately represents the total root environment. These relationships are discussed more fully by Chapman, 1960; various authors in Chapman (1966); Reuther and Smith, 1954; Reuther *et al.*, 1958; and DeVilliers and Beyers, (1961).

Soil analysis for nitrogen is of limited value for diagnostic purposes, even though some commercial laboratories use nitrate tests as guides. The available nitrogen in the soil is, for the most part, in nitrate form and varies from 0 to several hundred ppm of nitrogen as nitrate. If soil nitrogen, as nitrate, is more than 5 ppm, no nitrogen fertilizer need be added. However, less than 5 ppm does not necessarily indicate a deficiency, but rather that the nitrogen level should be checked by leaf analysis. Since nitrogen fertilizers

Table 4–2
ADEQUATE PHOSPHORUS TEST VALUES FOR SOIL SAMPLES TAKEN IN CITRUS GROVES ON ACID SANDY SOILS (FLORIDA)

Extraction Method*	Minimum adequate level (Pounds Per Acre 6 Inches)	
	P	P_2O_5
Acid ammonium acetate	22	50
Bray P_1	80	185
Bray P_2	130	300

Source: Reitz *et al.*, 1972.

* The acid ammonium acetate extracting solution is approximately 1 normal ammonium acetate adjusted to pH 4.8 with acetic acid. The Bray P_1 extracting solution is 0.03 normal ammonium fluoride. The Bray P_2 extracting solution is 0.03 normal ammonium fluoride and 0.1 normal hydrochloric acid.

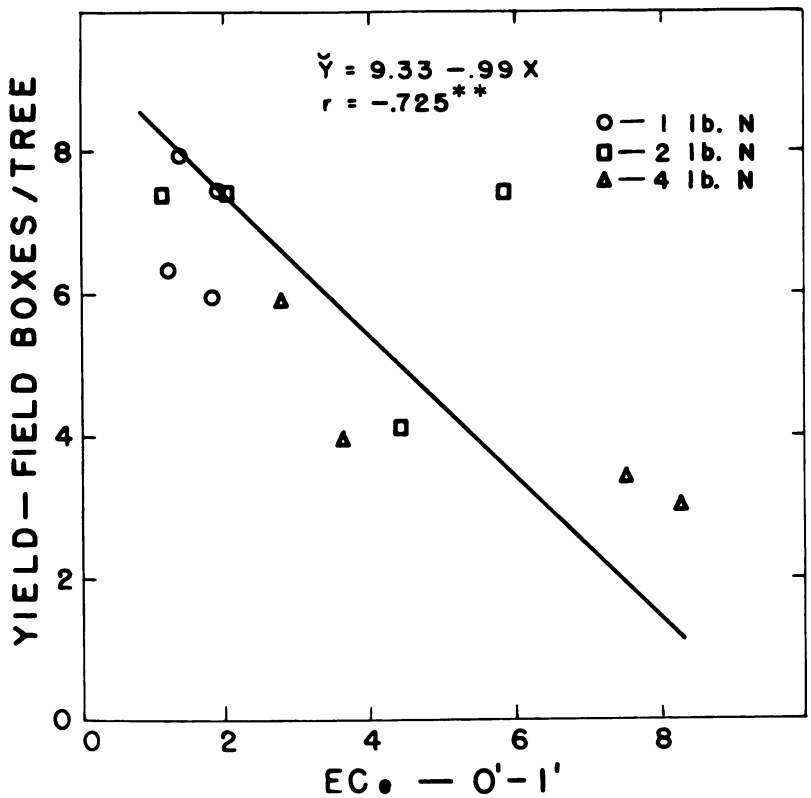

Fig. 4–3. Relation of nitrogen application to salinity yield of Valencia oranges.

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are salts, they add to the total salinity of the soil. Under conditions of a low rate of water infiltration such fertilizers may cause a reduction in yield because of the increase in salinity. Such an effect is shown in figure 4–3.

In a study of phosphorus-deficient citrus orchards in California, Aldrich and Buchanan (1954) found that deficiency was more closely associated with total phosphorus in soil than with water-soluble or acid-soluble phosphorus. Phosphorus had not been applied to these orchards and a total phosphorus of < 350 ppm was associated with phosphorus deficiency. In the sandy soils of Florida, with a history of phosphorus application, Spencer (1963) found a closer relation of tree response with extractable phosphorus than with total phosphorus. He reported that a value of 22 pounds of phosphorus per acre 6 inches (acid ammonium acetate extractable) was adequate. Reitz *et al.* (1972) reported that for the acid sandy soils of Florida there are sufficient data correlating tree performance with soil test values for phosphorus (extractable phosphorus by several methods) to make such soil tests useful supplements to general recommendations for phosphorus fertilization. Their suggested adequate levels are shown in table 4–2. In Israel, Heymann-Herschberg (1952) could draw no conclusion about the absorption of phosphorus by citrus trees by means of soil analyses (available phosphorus by Truog method.)

Soil analyses for phosphorus are of value in the evaluation of accumulation, movement, and redistribution of soil phosphorus. In a study covering 28 years in a Washington navel orange orchard on a sandy loam soil derived from granitic alluvium, Pratt, Jones, and Chapman (1956) and Pratt *et al.* (1959) reported that the loss of phosphorus, by removal with the fruit where no phosphorus had been applied, amounted to only about 2 per cent of the total phosphorus in the 0–36 inch layer of soil, whereas about 7 per cent had undergone absorption and redistribution by the trees. They suggest that the phosphorus accumulated in this manner is probably more available than the original phosphorus in the soil.

Soil analysis for potassium appears to be of only limited use in relation to the potassium nutrition of fruit trees (Lilleland and Brown, 1937). However, a number of workers have reported a significant correlation between leaf potassium and exchangeable potassium in the soil (Zubriski and Swingle 1950; Pratt, Jones, and Bingham, 1957; Harding, 1954; McColloch, Bingham, and Aldrich, 1957). Even so, the amount of potassium available to the trees depends on a number of other soil factors, and since leaf analysis gives an integrated measure of all of these factors, soil analysis would not be the preferred procedure for diagnostic purposes. However, where excesses of potassium or sodium are suspected, soil analysis would be the preferred procedure. Jones, Martin, and Bitters (1957) in a study of the effects of increasing exchangeable potassium or sodium or both on the growth of young lemon trees on various rootstocks, found that growth was decreased as the exchangeable potassium or sodium or both was increased and the reduction in growth was not closely related to the potassium or sodium or both content of the leaves.

In orchards where there is a need for potassium, it is often difficult to obtain an adequate increase in potassium in the trees from soil-applied potassium (Embleton *et al.*, 1969). The distribution of surface-applied potassium in the soil profile with time depends on such soil factors as cation-exchange capacity, potassium-fixation capacity, and the ratio of potassium to magnesium on the exchange complex of the soil (Page *et al.*, 1969). Soil analysis for these factors is helpful in determining the amount of potassium to apply and the method of application. Without knowledge of the magnitude of these factors, massive (20 or more lb of K_2SO_4 per tree) applications are frequently made. Such massive applications may cause an increase in salinity and thus limit an otherwise favorable potassium response (Embleton, Jones, and Page, 1967).

Copper may accumulate to toxic levels in acid sandy soils (Reuther and Smith, 1952; Smith and Specht, 1952) and soil analysis values of over 100 pounds of copper per acre 6 inches indicates potential toxicity (Reitz *et al.*, 1964).

Salt Excesses.—Citrus trees are particularly sensitive to high concentrations of salt, and soils containing them should be avoided. Soil analysis for diagnosing salinity problems is the accepted procedure. In an extensive study of soil characteristics in orange orchards of California, Harding and Chapman (1950) found that the one characteristic of high-producing orchards was low salinity. Figure 4–1 shows the relationship between salinity and yield of Washington navel oranges. Statistical evaluation showed 73 per cent of the variation of yield is attributable to the variation in soil salinity or closely-associated factors such as available moisture.

Soils high in salt commonly contain excess-

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ive amounts of sodium (the "black alkali" or "alkali" soils) or of the chlorides or sulfates of calcium and magnesium (the "white alkali" or "saline" soils). With rare exceptions, such as lands in humid regions invaded by sea water, harmful concentrations of salt constitute a problem of arid or semiarid regions. Salts seldom accumulate as a result of the weathering of soil particles in place. They are generally concentrated by evaporation from ground-water tables or from ponded surface water. Irrigation water is a very common source of salt. Failure to obtain leaching, owing to insufficient rainfall, unfavorable irrigation practices, or most commonly, poor drainage, ultimately results in salt accumulations. The importance of satisfactory soil permeability and the absence of a high water table, both of which factors are essential for adequate soil drainage, cannot be too strongly emphasized. The best irrigation waters contain some salt, and to prevent salt accumulation in the soil more water must be applied than is lost by evaporation and transpiration. The higher the salt content of the water, the more water that must be applied to prevent excessive accumulation of salt in the soil. Thus, the salt content of water determines the percentage applied that must be percolated through the root zone. Eaton (1958) objected to the term "salt balance" in this connection, since a balance can be maintained at various levels depending on the percentage of leachate (fig. 4–4). Hence, the term "salt balance" lacks exact meaning. With increased leaching rates, the average concentration of salt in the soil solution becomes progressively lower. The limit of dilution is the concentration of salt that exists in the irrigation water itself.

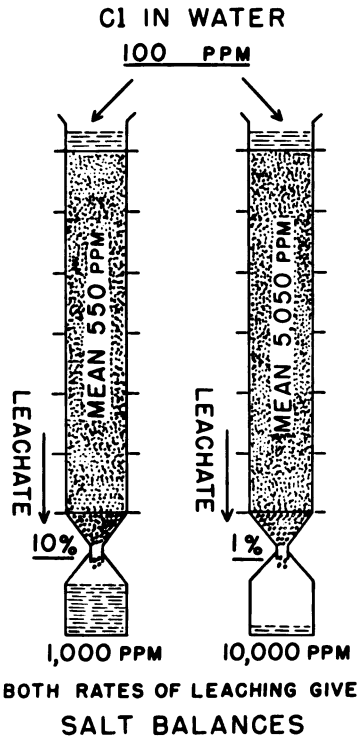

Fig. 4–4. Effects of leaching percentages on the concentrations of chloride in soil solutions and drainage waters. These idealized illustrations assume that crops were grown and their residues returned to the soil. (From Eaton, 1958.)

The various salts and their ions differ in specific effects. Boron is highly toxic to citrus in relatively low concentrations. Chlorides are also toxic, and chloride injury is observed in parts of many irrigated regions. Sulfates are toxic, especially under conditions of low nitrogen (Jones *et al.*, 1963). Special consideration should be given to sodium because of its relation to the formation of black alkali and to the permeability of soil. When the clay fraction of nonsaline soil has adsorbed an unduly large proportion of sodium and the proportion of adsorbed calcium and magnesium is correspondingly low, the soil structure deteriorates and the permeability of the soil is reduced, if not destroyed. Affected soils are frequently dark in color and have pH values between 8.5 and 10. Lithium may be excessive in some areas (Bradford, 1963; Hilgeman *et al.*, 1970).

Salty soils can be reclaimed under certain conditions if soil drainage is adequate. Reclamation and loss of use of the land, however, may prove costly. The most efficient reclamation requires the technical knowledge of a drainage engineer and the assistance of a soil chemist.

Soil Reaction.—In soil chemistry, the hydrogen ion has probably received more attention than any other single ion, and the end of research on this ion is not in sight (Jenny, 1961). Within rather wide limits, the acid or alkaline reaction of the soil, as indicated on the pH scale, is not of itself a very important factor in citrus-growing in California. Satisfactory crops are produced on various soils ranging from about pH 5 (moderately acid) to about pH 8.5 (moderately alkaline). In a field experiment, Jones and Cree (1954) found no effect on production of Washington navel oranges when the pH was reduced from 7.5 to 4.0 over a period of fifteen years. However, in the sandy soils of Florida, it is recommended that the pH be maintained between 5.5 and 7.0 (Reitz *et*

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al., 1972). This can be achieved by applying liming materials such as limestone or dolomite, although such applications are not effective to any great depth. Wander (1954) reported that subsoil acidity, resulting from the direct absorption of ammonium ions by deep roots, was not corrected by limestone applications. After an application of 16 tons of limestone per acre, the pH increased to a depth of only 30 inches over twenty-three years (Brown *et al.*, 1956).

The soil reaction may directly or indirectly influence plant growth (Truog, 1938). Direct effects are caused by the hydrogen ion. These include hydrogen-ion toxicity, altered effects of enzymes, and respiration effects. Indirect effects are on soil texture and hence on water infiltration, on solubility of certain plant nutrients, and on microbiological activity. In soil cultures, it is difficult to separate the direct from indirect effects of hydrogen ions. In solution cultures, Smith (1957) obtained poor growth of citrus seedlings at a maintained pH near 4. The foliage was normal in appearance but reduced in quantity. Root growth was severely reduced, and the laterals were stubby and occasionally had swollen root tips. In further work, Rasmussen and Smith (1959) concluded that at pH 4 hydrogen ions are directly toxic to the roots of citrus seedlings.

Under field conditions, the indirect effects of hydrogen ions appear to be more important than direct effects, especially within the range of pH usually encountered. The physical condition of the soil may be affected unfavorably by a low pH. In clay soils, deflocculation may result, which reduces water infiltration and soil aeration. After sixteen years of continuous use of ammonium sulfate in cultivated plots of Washington navel oranges, Aldrich, Parker, and Chapman (1945) reported a drop in soil pH from 7 to 4. There was a drastic decrease in macrospore space and water infiltration. Later, these same plots were changed from cultivation to nontillage, which resulted in a marked increase in water infiltration (Jones, Cree, and Embleton, 1961). Thus, it appears that mechanical stirring of the soil enchances the deflocculating effect of the hydrogen or ammonium ions. However, in laboratory studies with three soils, Martin and Richards (1959) found that variation of exchangeable hydrogen from 0 to 85 per cent exerted little influence on aggregation, bulk density, hydraulic conductivity, or moisture retention, but increasing exchangeable hydrogen increased the dispersing action of sodium, potassium and ammonium ions. Thus, the effect of pH on soil structure appears to be complex and is not fully understood.

The availability of all essential elements obtained by citrus from the soil may be affected in one way or another by soil pH. In citrus production, nutrition problems related to soil pH are usually concerned with the micronutrients. Copper has accumulated in excessive amounts in many grove soils in Florida and is toxic to the trees under conditions of low pH, but not toxic if pH is maintained at 6.5 or above (Reitz *et al.*, 1972; Reuther, Smith, and Scudder, 1953). In soils containing free calcium carbonate, the availability of the micronutrients may be greatly decreased, and symptoms of their deficiency may develop. Of these micronutrient deficiencies, iron deficiency is the most difficult to correct. Methods of correction of the micronutrient deficiencies are available, and these deficiencies are not now regarded so seriously as heretofore (see chap. 5). However, pH values of 8.5 or greater usually indicate the presence of excessive amounts of sodium salts.

Soil reaction also has a marked effect on soil organisms. At a pH of 4.0 to 4.5 the nitrification of ammonium is slowed or completely stopped. The citrus nematode is particularly sensitive to soil reaction. Van Gundy and Martin (1961) reported a reduction in numbers of citrus nematodes at pH values of 3.3 and 4.3 compared with values of 5.6 to 7.6.

Soil Sampling.—For soil sampling the orchard should first be inspected for uniformity, and unlike areas should be separately sampled. In an irrigated orchard, salts tend to accumulate at the margin of the wetted area, and between furrows in furrow-irrigated orchards. Any sampling procedure which seeks to determine mean composition should take and composite equal numbers of soil cores from each location. Chapman (1960) describes methods of soil sampling and handling suitable for citrus orchards. He suggests that for sampling an orchard of about 5 acres, eight sampling zones should be established—two located near the head of the irrigation run, two near the end of the irrigation run, and the others approximately $\frac{1}{3}$ and $\frac{2}{3}$ of the distance from the irrigation stands. At each sampling zone 4 cores should be taken, one in the tree furrow, one in the furrow crest adjacent to the tree furrow, and comparable cores in the furrow and crest at a point midway between the tree rows. This procedure can be modified for other orchard situations or if special problems are en-

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countered. If salinity is suspected, special sampling may be required since, under orchard conditions, salts are not uniformly distributed. The aim of soil sampling is to obtain samples that represent as nearly as possible the root environment.

Soil cores are usually obtained by the use of a ¾- to 1-inch tube. If the soil is too stony, sandy, or dry, posthole diggers, soil augers, or a spade may be used. Various depths representing most of the root zone should be composited separately. The usual depths sampled are 0- to 6- inches, 6- to 12- inches, and then separate foot horizons down to 4- to 6-feet. Contamination from soil surface materials should be avoided, and the soil samples should be placed in heavy paper or canvas bags, brought to a headquarters, and spread out on paper to dry. When air-dry, the soil should be worked through a 2 mm screen, discarding gravel but not soil crumbs. The soil can then be stored in cardboard cartons or glass jars. A one-quart sample of soil will suffice for all of the chemical tests.

Under more uniform soil conditions and cultures, such as those in Florida, Reitz *et al.*, (1972) suggest that in sampling a grove for pH, calcium, phosphorus, and copper, each soil sample should consist of a composite of about sixteen soil cores taken to a depth of six inches. One core should be collected from the dripline of sixteen different trees scattered throughout the grove. Separate samples should be taken for each part of a block that is visibly different in tree or soil characteristics. In no case should one sample represent an area larger than about twenty acres. If samples are to be collected once a year the best time would be in late summer. Each sample should be airdried, screened, and thoroughly mixed before analysis. The details of the chemical tests are beyond the scope of this discussion. The reader is referred to the literature or to a competent laboratory.

COVER CROPS

Cover cropping is the practice of growing a pure or mixed stand of densely-spaced herbaceous plants to cover the soil for part or all of the year. The plants may be incorporated into the soil by tillage, as in seasonal cover cropping, or they may be retained to reduce the risk of injury from soil erosion—an important problem in many hillside orchards. One effective method consists of permitting volunteer growth between rows with the tree rows kept clear by the use of herbicides (fig. 4–5). On some soils and in districts subject to torrential rains, the use of cover crops is essential to prevent irreparable damage from soil erosion.

When plants are incorporated into the soil by tillage, the organic matter added to the soil is called "green manure". This practice is sometimes termed "green-manuring". Cover crops may

Fig. 4–5. Erosion control by volunteer growth between tree rows. The tree rows were kept clean by the use of herbicides.

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thus be used as green manures, but other plant materials, such as alfalfa, hay, and bean straw may also be brought into an orchard, spread, and then worked into the soil as green manures. Such materials, however, originating outside the orchard, are more commonly known as bulky organic materials. Thus, although seasonal cover cropping and green-manuring are often treated as essentially the same thing, there is a distinction between them.

In some citrus-growing areas, particularly in Florida, it is desirable to grow a cover crop in summer, because this is the season of greatest rainfall. In other areas, such as California, winter is the time of greatest rainfall and possibly the only season when it is practical to grow a cover crop. There are large irrigated areas in California for which the water supply is insufficient to grow a cover crop in summer and also provide for the trees' moisture requirements.

The most favorable time to grow a cover crop depends upon local conditions and the season of growth, and varies widely in different citrus-growing areas.

Functions of a Cover Crop

The primary functions of a cover crop in an orchard are to improve soil structure, prevent soil erosion, improve nutritional conditions for the trees by rendering nutrients in the soil more available, add nitrogen, and remove excess water from heavy soils in years of excessive rainfall. Insofar as the citrus trees are concerned, however, cover crops are weeds and compete with the tree for moisture, nutrients, sunlight, and space. They may also be a source of insect and disease problems. Weeds can prevent proper movement of water during periods of excessive rainfall or during irrigation operations. They restrict movement of air and radiation of heat from the soil during cold periods. They may impede heating, spraying, and harvesting operations, and constitute a serious fire hazard (Kretchman and McGown, 1962). On cold nights a cover crop may lower the air temperature by as much as 11° F (Young, 1925). Thus, the decision on whether or not to use cover crops hinges on the relative importance of the factors discussed.

An improvement in soil structure after the growth of cover crops is common. Most noticeable, usually will be a quicker passage of irrigation water into the soil, or the greater ease with which the soil is tilled (table 4–3). The more mellow, friable condition of soils frequently cover-cropped sometimes presents a striking contrast to soils kept continuously in a state of clean culture. The periodical lack of cultivation associated with any annual cover-cropping practice—cultivation being discontinued for four to six months of each year—is probably an important factor in restoring soils more nearly to their original structure.

Table 4–3
INFLUENCE OF WINTER COVER CROPS ON WATER PENETRATION

Fertilizer Treatment	Mean Water Penetration in Feet*	
	No Cover Crop†	Cover Crop
Ammonium sulfate [$(NH_4)_2SO_4$]	1.15	1.55
Sodium nitrate [$NaNO_3$]	1.20	1.50
Calcium nitrate [$Ca(NO_3)_2$]	2.30	2.75

Source: Adapted from Parker and Jones (1951).
* Mean for five irrigations.
† Kept free of weeds by tillage.

Soil erosion in hillside orchards can more often be prevented by the growth of a cover crop than by any other practical means. Some soil types are so erodible that even with a grade of only 3 to 5 per cent there is an appreciable loss of topsoil if land is left bare during the rainy season. Erosion is especially critical if floodwaters from adjacent lands or highways pass over bare orchard soil soon after cultivation. Even a small amount of cover crop or weed growth has a tendency to spread the movement of surface water and slow down its rate of flow, greatly reducing its erosive power. Many desirable orchard sites thus require a cover crop throughout the rainy season.

Cover cropping is often the most practical method of procuring organic material. The relative benefits vary with soil type, fertilizer treatments previously applied, conditions of culture, and the primary crops grown after the cover crops. Where the use of organic matter apparently improves the fertility of soil, the growth of a cover crop is usually the most economical way to obtain a fair amount of it. In some citrus-growing districts, bulky organic fertilizers are much higher in price than other fertilizer materials; if natural rainfall or relatively cheap irrigation water can be used to produce the cover crop, this may mean a reduction in operation costs.

Decomposition of Cover Crops

To make the most effective use of cover cropping in maintaining soil fertility, it is desirable to understand several factors that influence the decomposition of cover crops.

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The decomposition of cover crops, as of any other organic matter in soils, is caused by soil microorganisms that use the organic matter as food. In the process of decomposition, various organic compounds are broken down and produce a number of byproducts. Of these the most important to the farmer are carbon dioxide, amino acids, and ammonia, the last two of which are quickly converted into nitrates. In addition, the aggregating effect on soil of most complex organic residues is largely dependent on the formation of binding substances (bacterial polysaccharides) during the decomposition of the residues by microorganisms (Martin, 1946).

Several factors influence the nature and rapidity of plant decomposition, but it is not practicable to review here the many investigations that have been made. Such a review may be found in Waksman and Tenney (1928).

Effect of Cover Crop on Soil Physical Condition

Soil Structure.—The incorporation of a cover crop or the addition of any organic matter affects the structure of most soils. The principle effect appears to be a higher percentage of water-stable aggregates than exists in soils to which no organic matter is added. The effect of mixing the tops of the cover crop with the tilled soil cannot be separated from the beneficial effect of the cover-crop roots, which extend below this layer of soil. Probably both are important, especially in the improvement of the physical condition of clay soils. Soils that are cover-cropped annually are friable, easily tilled, and readily distinguishable by field observation from comparable soils that have been subjected to a continuous system of clean culture by tillage.

The maintenance of the original structure of the soil is important in orchards in both irrigated and humid regions. In comparison to clean cultivation, one of the most obvious effects of cover-cropping observed by fruit growers in irrigated regions is that this practice is usually followed by a more rapid penetration of irrigation water. The presence of a cover crop in the orchard during the rainy season also reduces the loss of water by excessive runoff and temporarily improves soil conditions in the orchard. Results are somewhat comparable to the establishment of a sod on the land. The benefit of sod in improving soil structure has been noted by farmers and scientific observers for many generations.

Organic Content of Soil.—One cannot expect to increase the organic content of soil in a citrus orchard materially or permanently either by cover-cropping or applying large amounts of organic matter. Proebsting (1952) reported no increase in organic matter, total nitrogen, or moisture-holding capacity of the soil after twenty-five years of cover-cropping. He did find a marked improvement in soil structure as measured by the rate of water infiltration. Gramineous cover crops appear to be more effective than annual legumes in improving water infiltration (Williams and Doneen, 1960). Such improvement in soil structure is brought about by the action of microorganisms on the soil's organic matter (Geoghegan and Brian, 1948; Martin, 1943; Martin and Waksman, 1941).

While the organic content of soil in a citrus orchard cannot be increased permanently, this does not mean that the soil is devoid of organic matter. Pratt *et al.*, (1959) found 0.283 per cent of organic carbon in the 0- to 12-inch depth in a soil after thirty-eight years in citrus with no cover crops and no organic materials added. The organic carbon level had not changed during the thirty-eight years. The organic carbon in the soil may be temporarily increased by growing of cover crops or by the addition of organic materials such as manures or straws (Pratt *et al.*, 1959). This increase occurs only in the surface six inches of soil and thus may be of little direct value to deep-rooted citrus trees. Nevertheless, because of the improvement in soil aggregation, brought about by organic matter, indirect benefits of improved aeration and water relations extend into depths below six inches.

The cation-exchange capacity of a soil is due to both the mineral fraction and the organic fraction. The exchange capacity of the mineral fraction is not easily changed, but the exchange capacity of the soil may be increased by increasing the organic carbon. Pratt *et al.*, (1959) found that as much as 71 per cent of the cation-exchange capacity of the surface soil was in the organic matter. They found a highly significant correlation coefficient of 0.98 between per cent organic carbon and cation-exchange capacity. This is probably typical of a large number of relatively sandy soils.

From the point of view of the citrus grower, when cultivation is practiced, the addition of organic matter to soil by cover-cropping appears to be justifiable. The increase in organic carbon content of the soil may be relatively small, but the improvement in soil structure facilitates water infiltration.

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Nitrogen Fixation

Because nitrogen compounds are used so often in fertilizing citrus trees, an important practical consideration is the effect of nitrogen compounds in the soil upon the nitrogen-fixing power of legumes.

Numerous experiments have demonstrated the power of legumes to obtain the nitrogen necessary for growth from the air. Such experiments have been conducted with soils and sand cultures devoid of available nitrogen at the beginning of the experiment.

Many observations have been made under field conditions in an attempt to measure the amount of nitrogen actually added by the growth and incorporation of a legume cover crop in a soil. In summarizing several observations in this regard, Hopkins (1910, p. 217) stated:

> Clover and other legumes take available nitrogen from the soil in preference to the fixation of free nitrogen from the air, the latter being drawn upon only to supplement the soil's supply and thus balance the plant-food ration . . . the conclusion may be drawn that on normally productive soils at least one third of the nitrogen contained in legume plants is taken from the soil, not more than two thirds being secured from the air . . . when grown on richer soils, such legume crops leave the soil poorer in nitrogen; but on poor soils, furnishing less than the normal amount of available nitrogen, the growing of such legumes would enrich the soil in proportion to its poverty.

Other investigations indicated that relatively small amounts of available nitrogen in the soil may assist the fixation of atmospheric nitrogen by giving the legumes a good start in the early stage of their growth. According to the findings of Giöbel (1926, p. 119), however, relatively large amounts of available nitrogen in the soil may affect adversely or altogether inhibit the fixation of nitrogen from the air by legumes. This author lists 181 publications dealing, in large part, with legumes and nitrogen fixation. The majority of the investigations showed that relatively large amounts of available nitrogen in the soil depressed the nodule formation on various legume crops and reduced nitrogen fixation materially. In reporting his own investigations following a large number of experiments with alfalfa, Giöbel (1926, p. 118) stated: "The amounts of nitrogen fixed, in all cases, were inversely proportional to the amounts of soluble soil nitrogen at the disposal of the plants." The same observations were generally true with soybeans. Allos and Bartholomew (1955) reported that inorganic nitrogen depressed the nitrogen fixation by soybeans, peanuts, alfalfa, Lespedeza, Ladino Clover, and Birdsfoot Trefoil. In a lysimeter study (Chapman, Liebig, and Rayner, 1949), winter cover crops of purple vetch and sweet clover produced net gains of nitrogen of 150 pounds per acre per year. As the rate of application of inorganic nitrogen increased, the net gains of nitrogen from fixation decreased.

These findings have a direct bearing on the choice of a cover-crop plant. Legume crops such as clover or vetch have been used extensively as cover crops in citrus orchards. That they have the power of fixing nitrogen as well as supplying organic matter in an impoverished soil has been proved beyond question. However, most of the nitrogen fixed by legume cover crops becomes available to the citrus tree during the summer months and may therefore result in lowering of fruit quality (see discussion of nitrogen and fruit quality in chap. 5, p. 165).

Practical Considerations in Choice of Cover Crop

Tonnage of Organic Matter Produced.—The value of cover crops in maintaining fertility in citrus orchards is dependent, in part, upon the production of reasonably heavy tonnages of organic matter. The addition of nitrogen by fixation may in reality be considered of secondary importance. Inorganic nitrogen can be applied to the soil and economically converted into organic nitrogen by the cover crops, provided a good tonnage can be grown.

The tonnages of several winter cover crops, produced under field conditions rather than in an orchard, as reported by Mertz (1918, p. 10), are shown in table 4–4. The more or less vacant spaces in the tree rows, the effect of the shade of the trees, and the competition of such weeds as nettles and chickweed reduce materially the actual yields obtainable under orchard conditions. In order to arrive at a reasonable expectation under citrus-orchard conditions, the yields shown in table 4–4 should be reduced at least 30 per cent for young orchards eight to fifteen years old and as much as 50 per cent, or more, for orchards fifteen years old and older.

Competition by Weeds.—It is often difficult to obtain a satisfactory stand of leguminous cover crops in old orchards. The shade of the trees and competition by shade-enduring weeds sometimes reduce the cover-crop stand to a practical failure. This trouble is most apparent on soils heavily fertilized with stable manure, which

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Table 4–4
AVERAGE COMPOSITION OF SEVERAL WINTER LEGUME COVER CROPS, AND TONNAGE OF GREEN MATTER PRODUCED WHEN GROWN UNDER FIELD CONDITIONS

Plot	Green-Manure Crop	Green-Manure on Acre Basis (Average Tonnage)	Water (Per Cent)	Nitrogen in Green Weight (Per Cent)	Nitrogen Per Acre (Pounds)
1	Common vetch	12.0	82	0.538	129.6
3	Bur clover	12.7	84	0.637	161.3
5	Purple vetch	20.0	81	0.569	228.0
9	Canada peas	7.5	80	0.633	95.2
11	Tangier peas	13.7	86	0.494	135.6
13	Melilotus	13.7	80	0.556	152.0
15	Fenugreek	12.3	82	0.557	136.5
17	Lentils	12.1	75	0.650	157.3
	Average of eight legume plots	13.0	81	0.579	149.4

Source: Mertz (1918).

may naturally produce an abundance of weeds.

Many commercial citrus growers take the view that it is better to make sure of a heavy tonnage of a nonlegume than to be confronted with a light crop of legumes plus prevailing weeds such as chickweed and nettles (see chap. 3), making a light total tonnage. This view has much in its favor considering the relatively low price of inorganic nitrogenous fertilizers and the doubtful value of legumes as a means of fixing nitrogen in soil already rich in nitrates.

Attempts to grow legume crops, especially clovers or vetch, in full-bearing, thrifty citrus orchards, are invariably partial or complete failures. In such orchards, there are the alternatives of allowing various native weeds to grow as a cover crop or planting something that will compete successfully with or choke out the weeds. If the planting method is followed, a larger tonnage of organic matter will usually be grown, unless native weeds are hardy competitors such as malva and various wild mustards in California. Such native weeds as chickweed and nettles may completely choke out a crop of vetch or clover without producing a heavy tonnage of organic matter themselves. At present, there is no winter legume crop that produces a growth rapid enough to compete successfully with a dense infestation of chickweed or nettles.

The impracticability of using legumes as winter cover crops in mature citrus orchards has caused many California growers to turn to such crops as the various mustards, malva, and rape. These three crops contain relatively large percentages of nitrogen, and quickly decompose if turned under before reaching full maturity. All of these plants, especially the mustards, grow rapidly when sown in the fall. When mustard competes with nettles or chickweed, the mustard usually makes up the greater part of the final green tonnage. For this reason and because mustard may be planted at the beginning of the rainy season, it is frequently used as a cover crop in citrus orchards.

By fertilizing the orchard with the cheapest inorganic fertilizers and growing a cover crop of vigorous nonlegumes, the citrus grower obtains better results than by growing a medium or poor legume crop with only a small tonnage of organic matter, even though more nitrogen might be added to the soil by the latter method. We must stress again, however, that in young orchards where weeds have not become thoroughly established some legume cover crop can be used more profitably than any nonlegume crop. Melilotus clover or purple vetch are preferred for legume winter cover crops in California. For a summer legume cover crop in Florida, hairy indigo is excellent (Norris and Lawrence, 1962).

Culture and Disposal of Cover Crops

Winter Cover Crops.—In California, cover crops in citrus orchards are turned under in the late winter or very early spring. Hence, the crop should be planted early so that it will produce a satisfactory tonnage by that time. Five months are required to make a fair production with legume cover crops. If such a crop is to be turned

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under by February 15, it must be planted not later than September 15.

Mustard or malva, on the other hand, produce a fair tonnage in three months and can be planted in the warmer citrus districts as late as November 1 and still make a good crop by February 1. In fact, it may be desirable to postpone the planting of a mustard cover crop until October 15 to November 1. If planted much before then, the mustard is likely to be in full bloom by the end of December. This is an undesirable time to incorporate the cover crop into the soil, especially in orchards so situated that one of the reasons for cover cropping is the drying out of the soil moisture on land which is naturally too wet during the late winter. This is also too early, in the California districts, to turn under a cover crop on hillside land, where one of the advantages of a cover crop is erosion prevention. The alternative of allowing the early planted mustard to grow until February is a disadvantage, inasmuch as the full maturation of the crop to a tough, fibrous condition is not desirable because of its slow rate of disintegration. During orchard heating, the presence of a tall cover crop is a hindrance. With mustard waist-high from the middle of December to the end of the winter, orchard heating becomes a difficult and especially unpleasant task. For these several reasons, mustard may be a more satisfactory crop if planted from October 15 to November 1 than if planted earlier. In orchards where soil erosion is an important consideration, the planting of a cover crop at an early date is probably justified. If early-sown mustard cover crops interfere with orchard-heating operations, they can be mowed just before blooming; a secondary growth will occur later in the season. It should be noted that generally winter cover crops increase the cold hazard in an orchard which may therefore require more heating.

If the practical considerations in turning under a winter cover crop in a citrus orchard can be made to harmonize with the principles governing most effective use of such crops, good effects on the citrus are likely to follow. Just before such cover crops as melotus clover or vetch reach the blossoming stage, they produce about 80 per cent of their ultimate tonnage. They are still quite green and succulent, and at the same time have closely approached, but not fully attained, the maximum total nitrogen. This stage in the growth of the cover crop may be considered one of the most favorable at which to turn it under. Postponement of tillage for the added tonnage and total nitrogen that might be obtained by allowing the crop to mature does not seem justified in view of the resultant slower decomposition of the crop. Winter cover crops should be, and usually are, turned under a month or six weeks before the blooming of the orange trees. The annual application of nitrogen fertilizers should be made at this time. The rapid decomposition of the cover crop is essential. Casual observations indicate that incorporation of a winter cover crop into the soil at full maturity, in a dry, fibrous condition, has often done more harm than good. Fertilizer nitrogen might become non-biologically immobilized (Broadbent and Nakashima, 1967) and hence not readily available to the trees.

Summer Cover Crops.—Much that has been said of winter cover crops is also applicable to summer cover crops, with merely a change in the seasonal considerations. In regions of heavy summer rains, such as Florida, the use of summer cover crops is the most favorable method of producing organic matter as a supplement to fertilization. Because of the difficulty in growing legumes over a number of years on most sandy Florida soils, the cover crop usually consists of native grass and weeds. These may be chopped once during the summer. Then during the fall, after the summer rains are over, the cover crop is disked into the topsoil or plowed under. During the winter, the orchard is kept clean of weeds by an occasional disking (Camp, 1960). In Florida hairy indigo (*Indigofera hirsuta*) appears to be more productive than other legumes that have been tried as a cover crop for citrus (Norris and Lawrence, 1962). As a cover crop, torpedograss (*Panicum repens*) is to be avoided (Kretchman, 1962).

In some limited areas, sod culture has been used, but this generally requires more fertilizer and water.

The use of summer cover crops as a means of reducing the intake of nitrogen by grapefruit trees during the late summer and fall has been beneficial in one respect in Arizona (Martin, 1940): the trees thus treated have produced a higher proportion of smooth, thin-skinned fruit of high commercial quality than comparable trees growing in plots without summer cover crops. The growth of weeds, or at least the lack of cultivation, has been shown to be conducive to the production of fruit of good quality in Florida

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Table 4–5
AMOUNT OF SEED OF THE VARIOUS COVER CROPS TO SOW PER ACRE*

Crop	Seed (Pounds Per Acre)
Annual yellow sweet clover (*Melilotus indica*)	25
Canada field pea (*Pisum arvense*)	90
Colorado River hemp (*Sesbania macrocarpa*)	25
Common vetch (*Vicia sativa*)	80
Cowpea (*Vigna unguiculata*)	60–120
Crotalaria (*Crotalaria striata*)	8
Egyptian clover (*Trifolium alexandrinum*)	15
Hairy indigo (*Indigofera hirsuta*)	4–8
Natal grass (*Tricholaena rosea*)	6
Purple vetch (*Vicia atropurpurea*)	80
Rape (*Brassica napus*)	6
Small-seeded broad bean (*Vicia faba* var. *minor*)	25
Tangier pea (*Lathyrus tingitanus*)	60
Trieste mustard (*Brassica juncea*)	5
Velvet bean (*Mucuna utilis*)	30
White mustard (*Brassica alba*)	6

* For young orchards in which nearly all the land is planted to cover crop. Less seed is required per acre in older orchards, and modifications should be made accordingly.

(Lenfest, 1924). On the other hand, in much of the coastal region in California it is entirely impracticable to grow a summer cover crop, because a limited supply of irrigation water must be conserved during this rainless period.

Amount of Seed to Sow.—The amount of seed to sow per acre depends somewhat upon such factors as the quality of the seed, the season, and the age of the orchard. If seed is sown at a rather unfavorable season of the year, or at a time that is unfavorable with respect to the irrigation interval, it may be advisable to use a greater amount than would otherwise be required. A young orchard in which nearly all the ground is seeded will obviously take more seed than an older orchard in which, at the most, only two-thirds of the land is planted. The seedage shown in table 4–5 is recommended for young orchards in which nearly 100 per cent of the land is planted to cover crops. Modifications can be made as conditions warrant.

Methods of Sowing.—The preparation of a good seedbed is as important in sowing a cover crop as in growing any field or garden crop. With small-seeded crops such as the clovers, mustard, or rape, the seed may be sown on the well-prepared soil after the irrigation furrows are made. In actual practice, under orchard conditions, this will mean merely sowing it on the dry soil just before irrigation. If the irrigation water then is run in the furrows for a sufficient length of time to wet the surface soil thoroughly, the small seeds will settle in among the small lumps of wet soil and germinate before the soil can dry out. Thus, good cover-crop stands are obtained without harrowing the seed into the soil. Where the soil is sandy, or where the lateral movement of irrigation water on the surface soil is limited, it may be advisable to harrow the land lightly immediately after seeding and before furrowing.

For the larger-seeded crops such as the vetches or peas, it is advisable to cultivate the land to a depth of two to three inches to cover the seed. This may be done by a disk harrow set very shallow or equipped with rollers to prevent deep penetration. After this operation, the land should be furrowed out. The land then may be irrigated if the seed is sown during a dry period.

It is not commonly practicable to depend upon the rains to start the growth of the cover crop in arid sections. Care should be taken, however, not to use an excessive amount of water in starting cover-crop growth. Citrus trees may be injured by the application of much more water than is actually needed for tree growth.

Moisture Requirements.—If a cover crop is grown in a citrus orchard in a semiarid region, it will be necessary to apply some irrigation water in addition to that which would be necessary if clean culture was maintained. The actual amount of extra water made necessary by winter cover cropping in the various citrus districts of the arid or semiarid regions will vary greatly. The influencing factors are rainfall, humidity, temperature, soil types, and the particular cover crop grown. The average annual rainfall in the several citrus-growing districts in California, for example, varies from 3 inches to 24 inches. The extremes of annual rainfall occurring in these districts vary from 0.64 inch to 47 inches. Obviously, under such widely-varying conditions no definite amount of water can be recommended for application to a cover crop. The average annual rainfall of about 20 inches in the Upland, California, district may be expected to produce a good winter cover crop without extra irrigation water if the rains are favorably distributed. The rainfall in Mecca, California, however, may be less than 3 inches, and the winter cover crop is thus almost solely dependent upon irrigation water.

The average use of water in the citrus districts of southern California, excluding the desert area, varies from 12- to 36-acre-inches per

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acre per year. Usage may be as high as 100 acre-inches per acre per year in the desert area. A cover crop of 10 tons per acre may require 12 inches or more of water per acre to produce the crop. The probable amount of extra water necessary to grow a winter cover crop, over and above the normal water supply of the land, must be calculated with a knowledge of the probable rainfall, the soil type, and the usual amount of water required for each district. This extra water will vary all the way from none in some districts to 18 inches in others.

Disposal of Cover Crop.—The decay of a cover crop in an orchard soil is essential to its beneficial use. To promote decomposition, it is necessary that the material be incorporated with damp soil. It might be considered advisable, therefore, to turn under a cover crop to a depth somewhat in excess of that provided by the shallow summer cultivation. Care should be exercised in this operation, however, to make sure that plowing or disking is not so deep as to cut many roots of the citrus trees. All orchard disks should have rollers on them to prevent excessively deep penetration. It may sometimes be desirable to break down a large cover crop with a drag or disk before working the crop into the soil. This procedure makes plowing or final disking easier, and lessens the loss of water by transpiration—a result to be desired if the soil is drying out more rapidly than the cover crop can be turned under.

SOIL MANAGEMENT

There are a number of soil-management practices in use in citrus orchards in various parts of the world. The objectives of all such practices are to prevent weed competition with the citrus trees and to maintain a good physical condition of the soil. These practices may be classified as follows:

1. Clean cultivation.
2. Cultivation with winter cover crops.
3. Cultivation with summer cover crops.
4. No cultivation (nontillage), which may consist of (a) permanent sod, or (b) complete elimination of weeds by hand hoeing or herbicides (see chap. 3).

Thus, the citrus grower has the choice of a number of soil-management procedures. The procedure adopted will vary greatly with the natural conditions—the character of the soil, rainfall, prevalence of weeds, and other local factors. It may be well always to keep in mind that the functions of cultivation may be very different in an established orchard from what they are where annual crops are grown.

Citrus is grown in environments varying widely with respect to soil, climate, and economic conditions. It is therefore entirely impractical even to attempt to recommend a tillage procedure for citrus orchards in general. There are extremely gravelly soils in some California orchards, where any tillage of consequence is futile. There are extremely sandy soils in Florida, and to a lesser extent in California, where little tillage is needed. There are other soil types, especially the Ramona and Placentia loams in some California orchards, where tillage is needed but, if excessive, is harmful to the soil structure. This, in turn, may have an adverse effect upon the infiltration rate of irrigation water and rainfall. In addition, slow moisture infiltration is often a factor in causing soil-erosion problems even in orchards of only moderate slope. On the other hand, there are deep friable soils where tillage may be relatively harmless to structure.

Thus, the widest possible variety of cultivation practices may be found in orchards equally successful, or there may be no cultivation at all. In fact, several practical systems of orchard management have been developed, both in Florida and California, that do not involve cultivation or tillage. In this chapter, therefore, the principles involved in the cultivation of orchard soils have been dwelt upon, rather than definite recommendations, which naturally depend upon local conditions and experience.

Cultivation

In general, intensive cultivation is a destructive practice (Free, Browning, and Musgrave, 1940) and may even reduce the growth of cover crops (Flocker, Vomicel, and Vittum, 1958). That intensive cultivation reduces the yield of oranges is indicated by figure 4–6. In a comparison between clean cultivation and winter cover crops with summer cultivation, Parker and Jones (1951) reported approximately 30 per cent less yield under clean cultivation. Figure 4–6 also shows the accumulative, harmful effects of clean cultivation. It was approximately 18 years before the maximum effects of clean cultivation were fully developed.

The most common type of impairment of soil structure occurring in citrus orchards is the development of a compacted layer, called the plow sole, just below the cultivated zone. In a

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Table 4–6

SOIL COMPACTION (PLOW SOLE) AT VARIOUS DEPTHS IN CULTIVATED AND UNCULTIVATED AREAS OF A NUMBER OF SOUTHERN CALIFORNIA CITRUS ORCHARDS (UNCULTIVATED AREAS ARE OF SOIL BENEATH BRANCHES OF TREES)

Location of Sample	Volume Weight		Weight in Pounds Per Cubic Foot		Percentage of Pore Space	
	Cultivated Soil	Uncultivated Soil	Cultivated Soil	Uncultivated Soil	Cultivated Soil	Uncultivated Soil
			Ramona Soils (Average)			
Surface soil	1.57	1.41	98	89	41	47
Upper sole	1.80	1.52	112	95	32	43
Lower sole	1.61	1.46	100	92	39	45
Subsoil	1.57	1.37	98	85	41	48
			Hanford Soils (Average)			
Surface soil	1.40	1.27	88	79	47	52
Upper sole	1.65	1.50	103	93	38	43
Lower sole	1.56	1.43	97	89	41	46
Subsoil	1.36	1.34	85	84	49	49

Source: Data supplied by Charles F. Shaw and G. B. Bodman, Division of Soils, University of California, Berkeley, Calif.

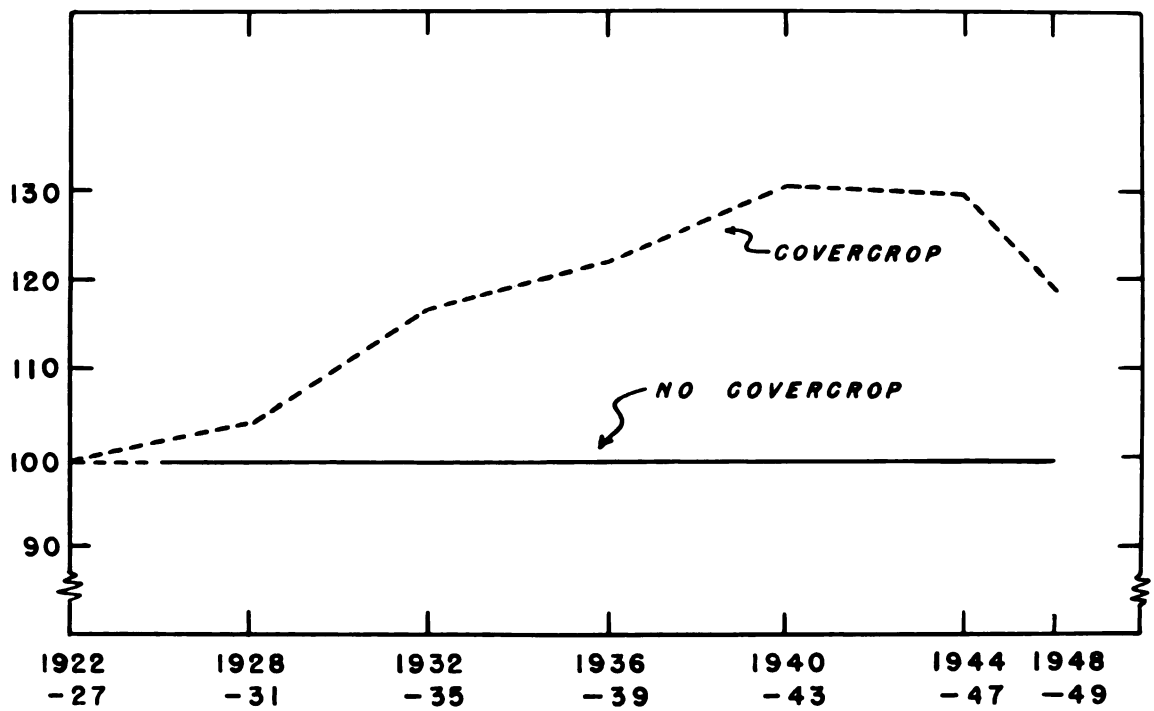

Fig. 4–6. Relative mean increase in total orange yields, resulting from the use of cover crops with four concentrated chemical sources of nitrogen over periods of four or two years from 1927 until 1949. The relative yields of plots which were without cover crops equals 100. An equal number of trees were fertilized with nitrate of lime, nitrate of soda, urea, and sulfate of ammonia under each system of culture. One pound of nitrogen was applied annually per tree from 1927 to 1939, and three pounds of nitrogen from 1940 to 1949. The lower relative yield of cover-cropped plots in 1948 and 1949 appears to be due to chance variations in the yields of 1949. (From Parker and Jones, 1951.)

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study of plow sole in a number of southern California citrus orchards, Shaw and Bodman[a] compared the condition of the cultivated soil with that of the uncultivated soil beneath the trees. Results are summarized in table 4–6. These data clearly indicate the degree of soil compaction at four different depths, as measured by increased volume weight, weight per cubic foot of soil, and percentage of pore space. It is apparent that cultivation and traffic have had a decidedly injurious effect on the structure of these soils. The loose mulch in the cultivated areas was about 6 inches deep. A careful examination of the colloid content showed no evidence of an accumulation of fine particles in that part of the profile which was directly below the cultivated zone. It was concluded that the plow sole was due to compaction probably caused by the combined effect of cultivation and traffic in the orchard, especially that which took place while the layer was still wet enough to be plastic.

Parker and Jenny (1945) studied the effects of traffic and disking on the rate of water infiltration and the soil structure in both wet soils and dry soils. The rate of water infiltration in these soils was greatly reduced by both operations, as compared with that in undisturbed soil. The damage to soil structure was greater with wet soil than with dry soil, however, and the increase in volume weight extended more deeply into the soils worked over when wet than into those worked over when dry. These investigators thus showed that tillage and traffic greatly increased the volume weight and impaired the permeability of the soil. They also showed that water penetration subsequent to these harmful operations was improved materially by letting the soil go through a period of several years without any tillage.

Striking effects have been observed in southern California citrus orchards as a result of reducing tillage operations to a minimum. In one Orange County orchard on Yolo loam, the rate of water infiltration increased twelvefold as a result of reducing tillage operations from an average of twelve to fifteen diskings a year to only two diskings annually. Similar, less striking results occurred in an orchard on Hanford gravelly sandy loam, near Pomona, California, where the rate of water infiltration was increased fourfold by greatly reducing cultivation. The ameliorating effect of reduced cultivation is not fully understood, because it may occur with or without the growth of weeds or cover crop. In a structurally degenerated soil, the restorative process appears to be essentially a result of the interaction of physical and biological factors (Telfair, Garner, and Miars, 1957).

The destructive effects of tillage on soil structure are not limited to the soils of the irrigated regions of California, Arizona, and Texas that are low in organic matter. Soils relatively high in organic-matter content, such as Porterville adobe in California, are also affected. A similar relation between tillage and soil structure has been reported in Oregon orchards (Stephenson and Schuster, 1942). In West Virginia, an experiment by Sudds and Browning (1941) indicated that cultivation reduced the organic-matter content, the percentage of the larger-sized soil aggregates, the noncapillary porosity, and the infiltration rate, but increased the volume weight and the dispersion ratio. Norris and Smith (1957) reported that minimum cultivation is the best cultural practice for grapefruit in Florida. A more general understanding of the detrimental effects of tillage will lead to a more reasonable cultivation program in most orchards.

The effects of tillage on aeration of orchard soils have been misunderstood. Aeration, as well as water penetration or permeability of a soil, depends upon the large pores, or the so-called noncapillary pore space. With most soils, one of the main effects of tillage on the zone just below the loose mulch is a reduction in the noncapillary pore space. This is especially hastened if the soil is worked when it is too wet. Compaction of the soil in the zone below the cultivated area is also increased by vehicular traffic when the soil is wet, and to a lesser degree when dry. Some of this traffic may be unavoidable, but every effort should be made to reduce it as far as is practicable.

Nontillage

Since cultivation is a destructive practice in orchard soils, the question arises: why cultivate? In the past it has been necessary to prevent weed competition. In attempting to correct the harmful effects of necessary cultivation, the work on cover crops and organic matter discussed in this chapter, and much not discussed because of lack of space, has been stimulated. Under orchard conditions, soil structure may not be main-

[a] Unpublished data in the files of Charles F. Shaw and G. B. Bodman, Division of Soils, University of California, Berkeley, California.

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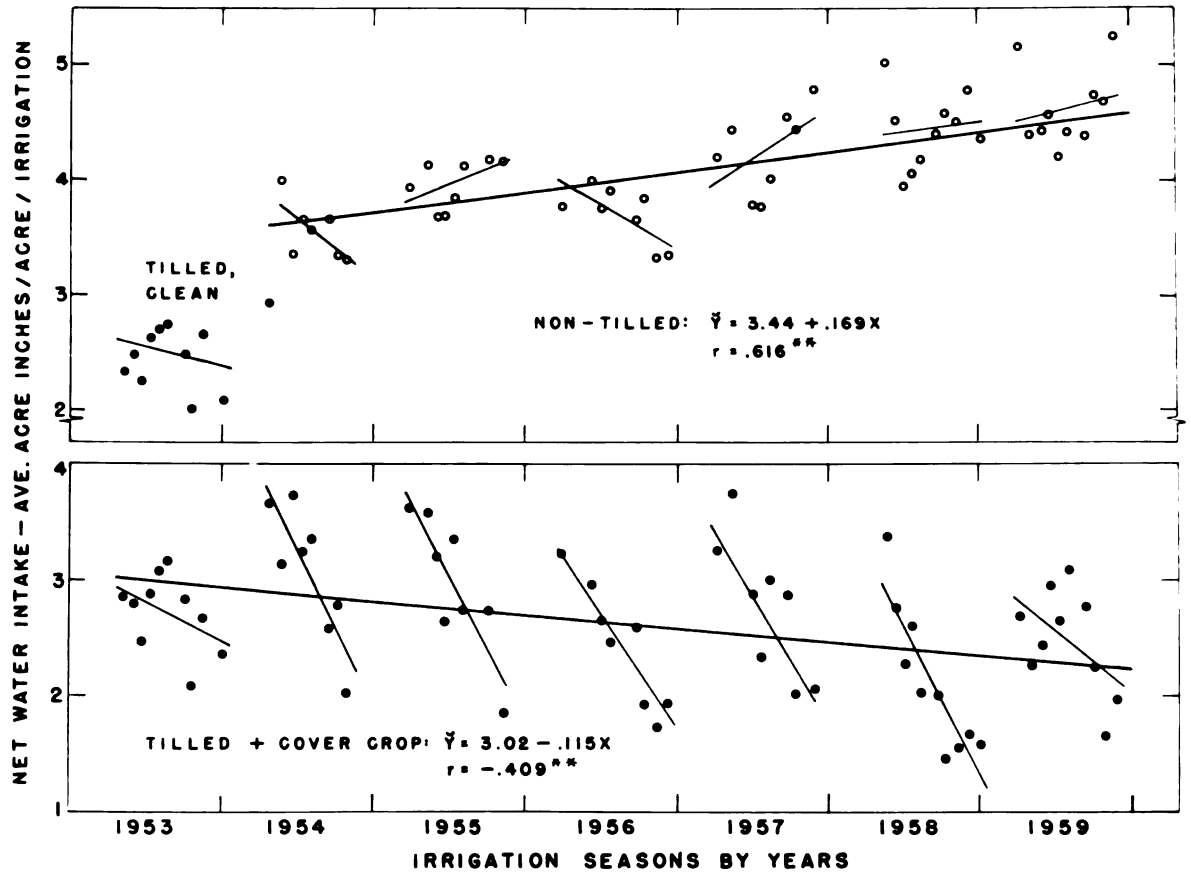

Fig. 4–7. Water intake as influenced by cultural practice and time. Each point represents one irrigation and the line for each group of points shows the trend for one irrigation season. (From Jones *et al.*, 1961.)

tained by the use of winter cover crops. Stolzy *et al.* (1960) pointed out that infiltration studies comprise a useful tool in evaluating the effects of different field-management practices on soil physical properties. Jones *et al.* (1961) found a gradual decrease in infiltration of water over a period of seven years (fig. 4–7) under a program of winter cover crops.

Since the development of herbicides it is no longer necessary to cultivate to control weeds (see chap. 3). The first nontillage system used in California was the "Hinkley system," first used in 1919 (Kimball *et al.*, 1951). This system makes use of the same irrigation furrows year after year, and all weed control is accomplished by lightly hoeing or scraping the surface soil when small weeds start to grow. Otherwise, the soil remains undisturbed. The occurrence of weed seeds in the orchard is also reduced by using only concentrated inorganic fertilizers. The citrus leaves partly fill in the wide, shallow furrows, and ac-

Table 4–7
INFLUENCE OF NONTILLAGE ON THE ROOTLET POPULATION OF ORANGE TREES

Soil Depth (Inches)	Rootlets* (Pounds Per Tree)		Distribution of Rootlets (Per Cent)	
	Tillage	Nontillage	Tillage	Nontillage
0– 6	0.28	3.29	2.3	14.5
6–12	3.08	8.80	25.3	38.7
12–24	3.82	5.40	31.4	23.7
24–60	5.00	5.26	41.0	23.1
0–60	12.18	22.75	100.0	100.0

Source: Adapted from Kimball *et al.* (1951).

* Each value is the mean of data from four trees with eight borings for each tree. The values do not include the 15 per cent of the total area that is immediately under the trees and never cultivated under either system. The nontillage values are significantly higher than the tillage values for the 0- to 6-inch depth at the 0.01 level and for the 6- to 12- and 0- to 60-inch depths at the 0.05 level of significance.

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Table 4–8
RELATION OF CULTURAL TREATMENTS TO NET WATER INTAKE BY SOIL AND YIELD OF A WASHINGTON NAVEL ORANGE ORCHARD

Treatment	Net Water Intake in Acre-Inches Per Acre Per Irrigation (Mean Values)			Yield in Pounds Per Tree Per Year (Mean Values)		
	1953–54	1954–55	1955–59	1953–54	1954–55	1955–59
Clean-cultivated until 1954, non-tilled after 1954	2.43	3.56	4.19	138	207	198
Cover cropped	2.71	2.97	2.55	183	218	163
Significance	•••	•••	•••	••	N.S.	•••

Source: Adapted from Jones *et al.* (1961).
N.S. indicates nonsignificance of difference of means.
•• Statistical significance at the 1 per cent level.
••• Statistical significance at the 0.1 per cent level.

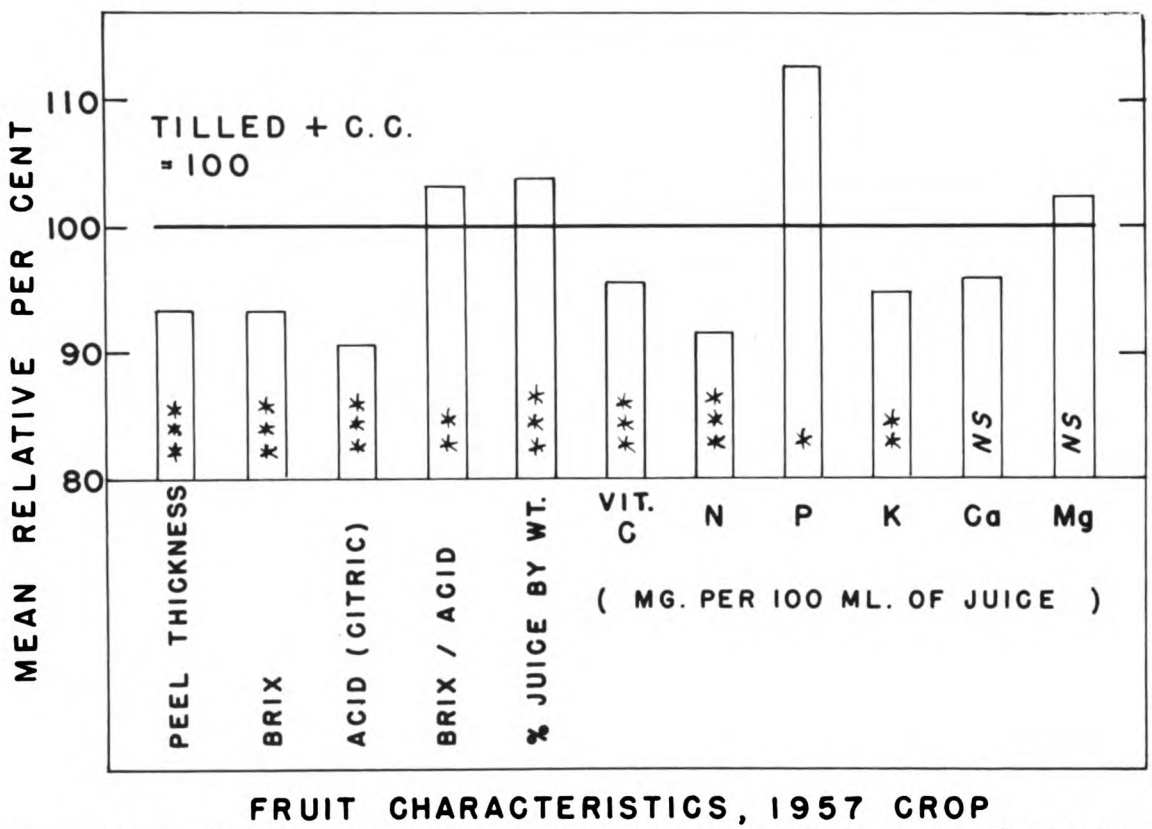

Fig. 4–8. Influence of cultural practices on relative peel thickness, juiciness, and juice composition. The bars represent the nontillage treatment values expressed as per cent of the corresponding values for the cover-cropped treatment. Symbols: *NS* = nonsignificant; * = significant at 5 per cent level; ** = significant at the 1 per cent level; * = significant at the 0.1 per cent level. (From Jones *et al.*, 1961.)**

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Fig. 4–9. Nontilled orchard. Three broad furrows permit traffic to move on the area between furrows. The accumulated trash tends to slow the water flow and increase the surface wetted.

cumulate under the trees; otherwise, the land is bare the year round.

This system is feasible where labor is inexpensive, but for the most part herbicides are used for the nontillage system of culture. Information obtained by surveys (Hinkley, 1939; Johnston and Sullivan, 1949; Kimball, Wallace, and Mueller, 1950; Moore, 1945; and Moore, 1946) indicates that on changing from tillage to nontillage an increase in water infiltration is the first noticeable result. Other observations indicate less runoff and less erosion and, in most cases, an increase in yields. In an orchard in which there was no noticeable plow sole development, Kimball *et al.* (1951) in a comparison between winter cover crop plus tillage with nontillage found that nontillage resulted in greater development of rootlets under orange trees (table 4–7). They reported a significant increase in weight of rootlets for the first foot and for the total of the first five feet of soil. Tillage did not induce deeper rooting. They found no effect of the cultural practices on the organic content of the soil, but nontillage resulted in a 17 per cent increase in yields. Patt (1958) reported excellent results with nontillage of citrus in Israel. In a six-year study with Washington navel oranges, Jones *et al.* (1961) reported an increase in water infiltration and in yield after changing from clean cultivation to nontillage (table 4–8). Plots on which winter cover crops were grown had a greater net water intake and greater yields than plots that were kept clean by disking. When the clean-cultivated plots were changed to nontillage, net water intake increased so that one year after the change the nontilled treatments had a greater net water intake than did the winter cover-cropped treatments, and yields became greater two years after the change. Fruit from the nontilled plots, compared with that of the cover-cropped plots, was larger and had a lower Brix (a measure of total soluble solids), a lower percentage of acid, less Vitamin C, less nitrogen, and less potassium, but a higher percentage of juice, more phosphorus in the juice, a higher Brix-acid ratio, and a thinner peel (fig. 4–8). During the six years of this study, trend line for net water intake was up for the nontilled treatments and down for the winter cover-cropped treatments (fig. 4–6).

Practical Consideration of Soil Management Practices

In most orchard soils, the objective of any soil-management program is to maintain soil structure. Most orchard operations, including tillage operations and passage of vehicular traffic through the orchard, compact the soil or cause the formation of plow sole. The harmful effects of orchard operations must be corrected to maintain soil conditions suitable for root growth. Hence, the practice of growing cover crops has developed. Organic matter added to the soil by cover crops or by manures or straws partiallly corrects the harmful effects of orchard operation. However, the problems of poor soil structure in orchard soils are mostly created by man himself and can be largely avoided. Tillage is perhaps the most harmful operation, and this is eliminated in the nontillage system. Damage from traffic can be minimized in furrow-irrigated orchards by furrow arrangement so that wheels run between furrows and hence do not compact the area through which water must penetrate (fig. 4–9).

In very sandy soils where structure is not a problem, the addition of organic matter as manures or from disked-under cover crops may have temporary beneficial effects on the water relations.

In conclusion, if the citrus grower will keep in mind the limited number of useful things that can be accomplished by tillage, and the fact that such operations almost invariably have some harmful effect on soil structure, he can no doubt develop an effective and economical program for his orchard.

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LITERATURE CITED

ALDRICH, D. G., and J. R. BUCHANAN. 1954. Soil phosphorus supply in healthy and phosphorus-deficient citrus orchards in southern California. Proc. Amer. Soc. Hort. Sci. 63:32–36.

ALDRICH, D. G., E. R. PARKER, and H. D. CHAPMAN. 1945. Effects of several nitrogenous fertilizers and soil amendments on the physical and chemical properties of an irrigated soil. Soil Sci. 59:299–312.

BATCHELOR, L. D., and H. J. WEBBER (eds.). 1948. The citrus industry, Vol. II. Production of the crop. Univ. Calif. Press, Berkeley and Los Angeles. 933 pp.

BRADFORD, G. R. 1963. Lithium in California's water resources. Calif. Agr. 17(5):6–8.

BROADBENT, F. E., and T. NAKASHIMA. 1967. Reversion of fertilizer nitrogen in soils. Soil Sci. Soc. Amer. Proc. 31:648–52.

BROWN, B. A., R. I. MUNSELL, R. F. HOLT, and A. V. KING. 1956. Soil reactions at various depths as influenced by time since application and amounts of limestone. Soil Sci. Soc. Amer. Proc. 20:518–22.

CAHOON, G. A., E. S. MORTON, and W. W. JONES. 1959. Effects of various types of nitrogen fertilizers on root density and distribution as related to water infiltration and fruit yields of Washington navel oranges in a long-term fertilizer experiment. Proc. Amer. Soc. Hort. Sci. 74:289–99.

CAMP, A. F. 1960. Citrus growing in Florida. *In:* Citrus industry of Florida. Fla. Dept. Agr. Bul. 2:228 pp.

CHAPMAN, H. D. 1960. Leaf and soil analysis in citrus orchards. Univ. Calif. Div. Agr. Sci. Ext. Serv. Manual. 25:53 pp.

——— (ed.). 1966. Diagnostic criteria for plants and soils. Univ. of Calif. Div. Agr. Sci., Berkeley. 793 pp.

CHAPMAN, H. D., S. M. BROWN, and D. S. RAYNER. 1947. Effects of potash deficiency and excess on orange trees. Hilgardia 17:619–48.

CHAPMAN, H. D., G. F. LIEBIG, and D. S. RAYNER. 1949. A lysimeter investigation of nitrogen gains and losses under various systems of cover cropping and fertilization, and a discussion of error sources. Hilgardia 19:57–128.

DEVILLIERS, J. I., and C. J. BEYERS. 1961. Leaf analysis as a guide to fertilization in commercial orange growing. *In:* Reuther, W. (ed.). Plant analysis and fertilizer problems. Pp. 107–19. Pub. by Amer. Inst. Biol. Sci., Washington, D.C.

EATON, F. M. 1958. Salts in irrigation waters and soils. Calif. Citrog. 44:4, 20–22.

EMBLETON, T. W., W. W. JONES, and A. L. PAGE. 1967. Potassium and phosphorus effects on deficient 'Eureka' lemon trees and some salinity problems. Proc. Amer. Soc. Hort. Sci. 91:120–27.

EMBLETON, T. W., W. W. JONES, A. L. PAGE, and R. G. PLATT. 1969. Potassium and California citrus. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. 3:1599–1603. Univ. of Calif., Riverside, Calif.

FLOCKER, W. J., J. A. VOMOCIL, and M. T. VITTUM. 1958. Response of winter cover crops to soil compaction. Soil Sci. Soc. Amer. Proc. 22:181–84.

FORD, H. W. 1954*a*. The influence of rootstock and tree age on root distribution of citrus. Proc. Amer. Soc. Hort. Sci. 63:137–42.

——— 1954*b*. Root distribution in relation to the water table. Proc. Fla. State Hort. Soc. 67:30–33.

FORD, H. W., W. REUTHER, and P. F. SMITH. 1957. Effect of nitrogen on root development of Valencia orange trees. Proc. Amer. Soc. Hort. Sci. 70:237–44.

FORD, H. W., and W. F. SPENCER. 1962. Combating iron oxide deposits in drain lines. Memo. Citrus Expt. Sta., Lake Alfred, Fla. 10 pp.

FREE, G. R., G. M. BROWNING, and G. W. MUSGRAVE. 1940. Relative infiltration and related physical characteristics of certain soils. U. S. Dept. Agr. Tech. Bul. 729:51 pp.

GEOGHEGAN, M. J., and R. C. BRIAN. 1948. Aggregate formation in soil: I. Influence of some bacterial polysaccharides on the binding of soil particles. Biochem. Jour. 43:5–13.

GIOBEL, G. 1926. The relation of soil nitrogen to nodule development and fixation of nitrogen by certain legumes. New Jersey Agr. Expt. Sta. Bul. 436:125 pp.

HARDING, R. B. 1954. Exchangeable cations in soils of California orange orchards in relation to yield and size of fruit and leaf composition. Soil Sci. 77:119–27.

HARDING, R. B., and H. D. CHAPMAN. 1950. Progress report on a study of soil characteristics in forty high-performance orange orchards in California. Soil Sci. Soc. Amer. Proc. 15:243–48.

HARDING, R. B., P. F. PRATT, and W. W. JONES. 1958. Changes in salinity, nitrogen, and soil reaction in a differentially fertilized soil. Soil Sci. 85:177–84.

HEYMANN-HERSCHBERG, LOTTE. 1952. Soil and leaf analysis as indicators of fertilizer requirements in Shamouti orange groves. Bul. Res. Coun. Israel. 1(4):20–37.

HILGEMAN, R. H., W. H. FULLER, L. F. TRUE, G. C. SHARPLES, and P. F. SMITH. 1970. Lithium toxicity in 'Marsh' grapefruit in Arizona. Jour. Amer. Soc. Hort. Sci. 95:248–51.

HILGEMAN, R. H., and C. W. VAN HORN. 1954. Citrus growing in Arizona. Univ. of Ariz. Agr. Expt. Sta. Bul. 258:36 pp.

HINKLEY, F. 1939. Growing oranges "Nature's way." Calif. Citrog. 24:390, 404–05.

HOPKINS, C. G. 1910. Soil fertility and permanent agriculture. Ginn and Company, Boston. 653 pp.

JENNY, H. 1961. Reflection on the soil acidity merry-go-round. Soil Sci. Soc. Amer. Proc. 25:428–32.

JOHNSTON, J. C., and W. SULLIVAN. 1949. Eliminating tillage in citrus soil management. Univ. Calif. Agr. Ext. Serv. Circ. 150:16 pp.

JONES, W. W., and C. B. CREE. 1954. Navel orange production as influenced by sulfur in the fertilizer program. Calif. Citrog. 39:212–14.

JONES, W. W., C. B. CREE, and T. W. EMBLETON. 1961. Some effects of nitrogen sources and cultural practices on water intake by soil in a Washington navel orange orchard and on fruit production, size, and quality. Proc. Amer. Soc. Hort. Sci. 77:146–54.

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JONES, W. W., T. W. EMBLETON, S. B. BOSWELL, M. L. STEINACKER, B. W. LEE, and E. L. BARNHART. 1963. Nitrogen control program for oranges and high sulfate and/or high boron. Calif. Citrog. **48**: 107, 128–29.

JONES, W. W., J. P. MARTIN, and W. P. BITTERS. 1957. Influence of exchangeable sodium and potassium in the soil on the growth and composition of young lemon trees on different rootstocks. Proc. Amer. Soc. Hort. Sci. **69**:189–96.

KIMBALL, M. H., A. WALLACE, and R. T. MUELLER. 1950. Changes in soil and citrus root characteristics with nontillage. Calif. Citrog. **35**:409, 432–33.

KIMBALL, M. H., A. WALLACE, R. T. MUELLER, and D. ZIMERMAN. 1951. Nontillage without cover cropping in a California citrus orchard. Proc. Amer. Soc. Hort. Sci. **58**:141–45.

KRETCHMAN, D. W. 1962. Torpedograss and citrus groves. Fla. Agr. Expt. Sta. Circ. **S-136**: 11 pp.

KRETCHMAN, D. W., and J. T. MCCOWN. 1962. Chemical weed control in citrus groves. Fla. Agr. Ext. Serv. Circ. **224**:19 pp.

LENFEST, R. E. 1924. Improvement in quality of citrus fruit. Proc. Fla. State Hort. Soc. **37**:68–71.

MARTIN, J. P. 1943. The effect of composts and compost materials upon the aggregation of the silt and clay particles of *Collington* sandy loam. Soil Sci. Soc. Amer. Proc. **7**:218–22.

——— 1946. Microorganisms and soil aggregation. II. Influence of bacterial polysaccharides on soil structure. Soil Sci. **61**:157–66.

MARTIN, J. P., and S. J. RICHARDS. 1959. Influence of exchangeable H and Ca, and of Na, K, and NH_4 at different H levels on certain physical properties of soils. Soil Sci. Soc. Amer. Proc. **23**:335–38.

MARTIN, J. P., and S. A. WAKSMAN. 1941. Influence of microorganisms on soil aggregation and erosion. II. Soil Sci. **52**:381–94.

MARTIN, W. E. 1940. Some effects of cultural practices upon tree composition, yield and quality of Marsh grapefruit in Arizona. Proc. Amer. Soc. Hort. Sci. **37**:68–75.

MCCOLLOCH, R. C., F. T. BINGHAM, and D. G. ALDRICH. 1957. Relation of soil potassium and magnesium to the magnesium nutrition of citrus. Soil Sci. Soc. Amer. Proc. **21**:85–88.

MERTZ, W. M. 1918. Green manure crops in southern California. Univ. Calif. Agr. Expt. Sta. Bul. **292**:31 pp.

MOORE, E. C. 1945. Non-tillage weed spray program in Tulare County. Calif. Citrog. **30**:280–81.

MOORE, P. W. 1946. Grass roots view on non-cultivation. Calif. Citrog. **31**:201, 218–19.

NORRIS, R. E. and F. P. LAWRENCE. 1962. Hairy indigo as a cover crop in Florida citrus. Fla. Agr. Ext. Serv. Circ. **227**:10 pp.

NORRIS, R. E., and P. F. SMITH. 1957. Cultivation trials in a young bearing grapefruit grove on sandy ridge soil. Proc. Fla. State Hort. Soc. **70**:28–31.

PAGE, A. L., T. J. GANJE, T. W. EMBLETON, and W. W. JONES. 1969. Soil factors influencing the correction of K deficiencies on citrus in California. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. **3**:1605–12. Univ. of Calif., Riverside, Calif.

PARKER, E. R., and H. JENNY. 1945. Water infiltration and related soil properties as affected by cultivation and organic fertilization. Soil Sci. **60**:353–76.

PARKER, E. R., and W. W. JONES. 1951. Effects of fertilizers upon the yields, size and quality of orange fruits. Univ. Calif. Agr. Expt. Sta. Bul. **722**: 57 pp.

PATT, JACOB. 1958. Experiments in non-tillage of citrus in the coastal zone of Israel. Le Livre du IV^{eme} Congr. Intern. Agrum. Mediter. [Tel Aviv, Israel] **1956**:219–30.

PRATT, P. F., R. B. HARDING, W. W. JONES, and H. D. CHAPMAN. 1959. Chemical changes in an irrigated soil during 28 years of differential fertilization. Hilgardia **28**:381–420.

PRATT, P. F., W. W. JONES, and F. T. BINGHAM. 1957. Magnesium and potassium content of orange leaves in relation to exchangeable magnesium and potassium in the soil at various depths. Proc. Amer. Soc. Hort. Sci. **70**:245–51.

PRATT, P. F., W. W. JONES, and H. D. CHAPMAN. 1956. Changes in phosphorus in an irrigated soil during 28 years of differential fertilization. Soil Sci. **82**: 295–306.

PROEBSTING, E. L. 1952. Some effects of long continued cover cropping in a California orchard. Proc. Amer. Soc. Hort. Sci. **60**:87–90.

RASMUSSEN, G. K., and P. F. SMITH. 1959. Effects of H-ion concentration on growth of pineapple orange seedlings in alternate solution and water cultures. Proc. Amer. Soc. Hort. Sci. **73**:242–47.

REITZ, H. J., C. D. LEONARD, I. STEWART, R. C. J. KOO, C. A. ANDERSON, R. L. REESE, D. V. CALVERT, and P. F. SMITH. 1972. Recommended fertilizers and nutritional sprays for citrus. Fla. Agr. Exp. Sta. Bul. **536B**: 24 pp.

REITZ, H. J., and W. T. LONG. 1955. Water table fluctuation and depth of rooting of citrus trees in the Indian River area. Proc. Fla. State Hort. Soc. **68**: 24–29.

REUTHER, W., T. W. EMBLETON, and W. W. JONES. 1958. Mineral nutrition of tree crops. Ann. Rev. Plant Physiol. **9**:175–206.

REUTHER, W., and P. F. SMITH. 1952. Iron chlorosis in Florida citrus groves in relation to certain soil constituents. Proc. Fla. State Hort. Soc. **65**:62–69.

REUTHER, W., P. F. SMITH, and G. K. SCUDDER. 1953. Relation of pH and soil type to toxicity of copper to citrus seedlings. Proc. Fla. State Hort. Soc. **66**:73–80.

SITES, J. W., L. C. HAMMOND, R. G. LEIGHTY, and W. O. JOHNSON. 1961. Information to consider in the use of soils of flatwoods and marshes for citrus. Fla. Agr. Expt. Sta. Circ. **S-135**:35 pp.

SMITH, P. F. 1957. Studies on the growth of citrus seedlings with different forms of nitrogen in solution cultures. Plant Physiol. **32**:11–15.

——— 1966. Leaf analysis of citrus. *In:* Childers, N. F. (ed.). Fruit Nutrition. 2nd ed. Chap. 8, pp. 208–28. Horticultural Publications, Rutgers Univ., New Brunswick, New Jersey.

SMITH, P. F., and A. W. SPECHT. 1952. Heavy-metal nutrition in relation to iron chlorosis of citrus seedlings. Proc. Fla. State Hort. Soc. **65**:101–08.

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SPENCER, W. F. 1963. Phosphorus fertilization of citrus. Fla. Agr. Expt. Sta. Bul. **653**: 48 pp.

SPENCER, W. F., R. PATRICK, and H. W. FORD. 1963. The occurrence and course of iron oxide deposits in tile drains. Soil Sci. Soc. Amer. Proc. **27**:134–37.

STEPHENSON, R. E., and C. E. SCHUSTER. 1942. Changes in orchard soil properties resulting from long continued tillage. *In:* Abstracts of papers presented at the meeting of the Western Society of Soil Science. Pp. 16–17. Univ. Utah, Salt Lake City. (Processed.)

STOLZY, L. H., T. E. SZUSZKIEWICZ, M. J. GARBER, and R. B. HARDING. 1960. Effects of soil management practices on infiltration rates. Soil Sci. **89**:338–41.

SUDDS, R. H., and G. M. BROWNING. 1941. The effect of soil-management methods on certain physical and chemical properties in relation to the infiltration rates in West Virginia orchards. Proc. Amer. Soc. Hort. Sci. **39**:38–46.

TELFAIR, D., M. R. GARNER, and D. MIARS. 1957. The restoration of a structurally degenerated soil. Soil Sci. Soc. Amer. Proc. **21**:131–34.

TITUS, J. S., and D. BOYNTON. 1953. The relationship between soil analysis and leaf analysis in eighty New York McIntosh apple orchards. Proc. Amer. Soc. Hort. Sci. **61**:6–26.

TRUOG, E. 1938. Soil acidity and liming. U. S. Dept. Agr. Yearbook **1938**:563–80.

VAN GUNDY, S. D., and J. P. MARTIN. 1961. Influence of *Tylenchulus semipenetrans* on the growth and chemical composition of sweet orange seedlings in soils of various exchangeable cation ratios. Phytopathology **51**:146–51.

WAKSMAN, S. A., and F. G. TENNEY. 1928. Composition of natural organic materials and their decomposition in the soil. III. The influence of nature of plant upon the rapidity of its decomposition. Soil Sci. **26**:155–71.

WANDER, I. W. 1954. Sources contributing to subsoil acidity in Florida citrus groves. Proc. Amer. Soc. Hort. Sci. **64**:105–10.

WILLIAMS, W. A., and L. D. DONEEN. 1960. Field infiltration studies with green manure and crop residues on irrigated soils. Soil Sci. Soc. Amer. Proc. **24**: 58–61.

YOUNG, F. D. 1925. A further study on the relation between cover crops and orchard temperatures. U. S. Monthly Weather Rept. **53**:387–91.

YOUNG, T. W. 1953. Soil moisture relations in the coastal citrus areas of Florida. Fla. Agr. Expt. Sta. Bul. **526**: 38 pp.

ZUBRISKI, J. C., and C. F. SWINGLE. 1950. Potassium content of Montmorency cherry leaves in relation to curl-leaf and to exchangeable soil potassium. Proc. Amer. Soc. Hort. Sci. **56**:34–39.

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CHAPTER 5

Citrus Fertilization

TOM W. EMBLETON, HERMAN J. REITZ, and WINSTON W. JONES

CITRUS WAS UNDOUBTEDLY cultivated before the advent of recorded history. As civilization developed, citrus planting became more intensive, first in areas near its natural habitat and then in other sections of the world. Both the more intensive cultivation and the spread of citrus to new lands created problems that had not existed, at least to the same extent, in the undisturbed native habitat. Among these were nutritional disorders, including nutrient deficiencies and excesses.

Until the early twentieth century, citrus fertilization was essentially an art, but since that time, research has made it possible to fertilize citrus on a sounder scientific basis. Early research investigations were aimed primarily at correcting deficiencies and increasing fruit yields. Today, however, we are not satisfied with high yield alone; we also strive for top quality and favorable fruit size.

This chapter summarizes current knowledge about the correction of nutritional disorders and the mineral nutrients required under commercial orchard conditions to maintain a high productivity of quality fruit of favorable size.

Chemical, physical, and microbiological properties of soils change gradually during the long life of a citrus orchard (Jones, Cree, and Embleton, 1961; Martin, 1950; Pratt *et al.*, 1959). Fertilizer practices that correct deficiencies or result in other favorable responses when an orchard is first planted on virgin soil may be unnecessary or even harmful in later years. Salts or elements from fertilizers, soil amendments, manures, irrigation water, and various sprays may accumulate in the soil in soluble or exchangeable forms and have adverse effects on the tree. Some adverse effects and their causes are now clearly understood, and appropriate steps can be taken to correct these effects or prevent their development.

A good example of an initially beneficial practice that became detrimental is found in the history of copper usage in Florida. Many sandy soils in central Florida in their natural condition contained less than 5 pounds of total copper per acre in the top 6 inches of soil (about 2.5 ppm). More than half a century ago, it became evident that citrus trees growing on these soils responded to copper applications (Floyd, 1914). Thereafter, copper fertilization became routine, although for many years the nature of its action was not understood. Copper also was used in fungicidal sprays. Copper therefore accumulated in many orchards, and by 1950 reached toxic levels of 200 pounds or more per acre in the top 6 inches of soil. Present recommendations are that copper be used only where the level in the soil is low, that soils high in copper be limed to pH 6.0 or over, and that iron chelates be used to control copper-induced iron chlorosis (Reitz, 1961; Reitz *et al.*, 1972; Reuther and Smith, 1952*a*, 1953; Smith and Specht, 1952; Stewart and Leonard, 1952*a*, 1952*b*, 1957). Thus, research programs must be concerned about excesses developing from cumulative effects of fertilizers as well as about the correction of deficiencies.

The most desirable fertilizer program leads to optimum economic usage of fertilizer and avoids deficiencies and excesses. Excessive fertilizer use is not only expensive, but it may also in-

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terfere with the nutrition or availability of other fertilizer elements, create soil conditions that take years to correct, or contribute to the pollution of water supplies. Every effort must be made to keep citrus soils productive for future generations. To formulate a sound fertilizer program, one must consider what takes place in the soil and in the citrus tree.

ESSENTIAL ELEMENTS FOR PLANT GROWTH AND THEIR SOURCE

Seventeen elements are recognized as essential for plant growth: carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B), iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), molybdenum (Mo), chlorine (Cl), and sodium (Na). Of the inorganic elements, eleven (nitrogen, phosphorus, potassium, calcium, magnesium, boron, iron, zinc, manganese, copper, and molybdenum) have been found to be deficient for citrus growth under field conditions in one or more locations. Sulfur deficiency has been reported only from controlled cultures (Chapman and Brown, 1941). As yet, neither chlorine nor sodium deficiency have been found in citrus.[1]

Carbon is supplied to the plant primarily from carbon dioxide in the air. During the photosynthetic process, carbon dioxide combines with water to form the organic material which is the plant food. Although little can be done about it from a practical standpoint, carbon dioxide probably becomes limiting at times for maximum growth of the citrus tree. Miller (1938) cited reports showing that the growth of many plants was increased substantially by carbon dioxode fertilization, that is by increasing the carbon dioxide concentration in the air around the above-ground portion of the plant. There has been renewed interest in the practical aspects of carbon dioxide fertilization of greenhouse plants (Wittwer, 1967).

In addition to supplying hydrogen to the plant, water has many functions. The effects of a stress for water, however, become apparent long before a deficiency of hydrogen *per se.*

The plant oxygen supply comes from air and water. Because of an abundant oxygen supply in the air, little, if any, benefit is obtained by increasing the oxygen concentration in air surrounding the above-ground portion of the plant. However, oxygen concentration in soil air is much lower than in air above ground. In poorly drained soils, oxygen frequently becomes limiting for root growth. This condition, which can be very serious in citrus orchards, is discussed in more detail in Chapter 4, p. 101.

Approximately 95 per cent of the dry weight of a citrus tree, or about 98 per cent of the fresh weight, is made up of carbon, hydrogen, and oxygen. It is the elements which constitute the remaining 5 per cent of the dry weight that are most important in orchard fertilization.

THE PURPOSE OF FERTILIZATION

The purpose of fertilization is to supplement the supply of essential elements in the soil, thus increasing the economic return from the harvested portion of plants. This may be the leaf, the stem, the root, the oil, the sugar, the ascorbic acid, or the fruit, as with citrus. A fertilizer program producing the largest tonnage of leafy material may not necessarily produce the greatest fruit tonnage. A program for citrus producing the largest quantity of citric acid per acre may not necessarily produce the largest quantity of soluble solids per acre. A program producing the greatest tonnage of citrus fruit per acre may not necessarily produce the highest economic return or the best attainable fruit quality. Thus, the specific objective must be considered in formulating a sound fertilizer program.

When a citrus grower fertilizes an orchard and spends money for fertilizer materials, he acts upon the probability that the resulting increased crop yield, larger fruit size, improved fruit quality, or combinations of these three factors will repay the money expended and bring an additional return. Materials purchased should be those which experience has shown likely to return the greatest profit per dollar expended. The largest gross return per acre, however, may not realize the greatest profit per acre in terms of money spent for fertilization, since the relative profitableness may follow the "law of diminishing returns."

There is no evidence that a condition of balance (maintenance of a narrowly specific set of ratios among the various fertilizer elements) is essential in citrus fertilization. As early as 1919, Hoagland concluded there was insufficient evidence to prove that a plant requires any very

[1] For a description of deficiency symptoms and functions of the essential elements see Jones and Smith (1964), Pratt (1958), and Chapman (1968).

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specific ratio of ions or elements for optimum yield even within wide limits, provided the total supply and concentration of essential elements are adequate. Later research has not changed this conclusion (Smith, 1962*a*). In any event, it is impossible to maintain any specific "balance" in soil.

It is fortunate indeed for the grower that fertilization does not require adding to each soil all the elements needed by the plant. Many of the elements occur in adequate amounts.

As a general rule in supplementing soil deficiencies, one should purchase fertilizer materials that contain the most of the desired fertilizer elements for the money expended. Because of indirect effects of fertilizers, there are instances where this would not be desirable, however, and there is no uniform fertilizer treatment that can be prescribed for all citrus-growing areas. Deficiencies in soils, physical characteristics and chemical composition of the soil, previous treatment of the orchard, impurities in irrigation water, climatic conditions such as rainfall, and the economics of each situation are among many factors which must be considered.

DETERMINING FERTILIZER NEEDS

Many approaches have been used to determine citrus fertilizer needs. Among these are grower experience, using programs of successful growers in the area as models, replacing amounts of certain nutrients removed in fruit, symptomatology, applying results from surveys and greenhouse and field experiments, and soil and leaf analysis. There is some evidence that fruit analysis eventually may be used to good advantage. All of the approaches have value and should be considered.

Certainly, there is no substitute for enlightened experience. But an ultraconservative attitude toward change in fertilizer practice will not be in the grower's best interest. A successful citrus grower is usually one with an open mind and keen powers of observation. It has already been pointed out that physical, chemical, and microbial properties of citrus soils change under continued cultivation. Even the keenest observer may be unable to detect differences in the field that have a great influence on returns from a grove. Detailed experiments may be necessary to delineate these differences with a reasonable degree of confidence.

Using the program of a successful grower in an area as a model may be advantageous. However, there are some citrus soils that will produce excellent crops of fruit with a program that would be undesirable on a different soil in the same area. Thus, this approach can be dangerous.

One school of thought advocates returning to the soil the amounts of constituents that are removed in the fruit. For the most part, this approach is unsound. For example, Pratt, Jones, and Chapman (1956) calculated that over a twenty-eight-year period, loss of phosphorus by removal in the fruit from the highest yielding experimental trees amounted to only 2 per cent of total phosphorus in the 0-to-36-inch layer of soil, whereas about 7 per cent had undergone absorption and redistribution by the trees. The redistributed phosphorus is probably more available to the tree than original phosphorus in the soil. Under these conditions, phosphorus applications during the twenty-eight-year period have not been beneficial, and it is unlikely phosphorus additions will be needed in this orchard until some time in the distant future. In Florida, many citrus groves have a phosphorus supply in the soil that will last many years (Reitz *et al.*, 1972; Spencer, 1963).

Symptomatology can be used to good advantage in determining some fertilizer needs. However, in certain instances, a program that prevents deficiency symptoms from developing would be preferable to one that employs corrective measures after deficiency develops. When zinc, manganese, magnesium, iron, molybdenum, or copper become deficient, characteristic symptoms develop and a trained individual can identify the deficiency. However, two or more deficiencies may occur at the same time, as well as combinations of deficiencies and excesses and complications of these with symptoms of disease, pest injury, herbicide injury, or unfavorable soil conditions. When this happens, diagnosis of the problem by visual inspection may be difficult, if not impossible. Also, this approach does not expose uneconomically high use of many of the fertilizer elements, and thus permits wasteful programs to go undetected.

Results from surveys are enlightening, but may be misleading. For example, a survey may indicate that growers who use the greatest amounts of fertilizer obtain the largest yields, whereas, in fact, growers obtaining the largest yields have more money to buy fertilizer and therefore use more.

Knowledge of results of greenhouse and field experiments can be helpful in planning a fertilizer program. Greenhouse experiments have

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been of value in identifying, under controlled conditions, symptoms of specific nutritional deficiencies and excesses. Where soils and cultural operations are similar over a wide area, such as in central Florida, a field experiment on rates of nitrogen, for example, may suggest a nitrogen program that can be applied to a large area. In California, where many types of soils and cultural operations exist, results from studies of various rates of nitrogen under one cultural program may be of limited value. However, if information on plant and soil analysis is also obtained, then results are applicable to a wide range of conditions. Soil analysis was covered in Chapter 4 and plant analysis will be covered in Chapter 6.

SOIL AND CLIMATE

Most evidence now indicates that the optimum nutritional level of fertilizer elements in the trees is about the same for a given citrus variety, regardless of soil and climate. However, ability of trees to obtain these elements in proper quantities is influenced by many factors, among which are soil and climate.

Generally, sands are less fertile than clays. In a given volume of sand, there is much less total surface than in the same volume of clay. In general, the greater the total surface in a given volume of soil, the greater the number of sites where positively charged cations, such as calcium, magnesium, potassium, sodium, ammonium, aluminum, and hydrogen can be held by negatively-charged soil particles. Cations chemically combined with the soil in this manner resist leaching, but can be replaced with other cations and are available to plants. The capacity of a soil to adsorb cations is called *cation-exchange capacity*, which is expressed in milliequivalents per 100 grams of soil. Sands have low- and clays have high-cation-exchange capacities. Soil humus has a cation-exchange capacity considerably higher than clays and is important in any soil's exchange complex.

Problems associated with improper fertilizer practice generally develop more rapidly on sandy soil with a low-cation-exchange capacity than on clay soil with a high-cation-exchange capacity. For example, one of the strongest reciprocal effects among nutrient elements in tree crops is that of high potassium inducing magnesium deficiency. Excessive use of potassium on sandy soil usually will induce magnesium deficiency more rapidly than the same usage of potassium on clay soil. Generally, clay soils withstand more fertilizer abuses than sandy soils; however, after a problem develops from an improper fertilizer program, it usually can be corrected more rapidly in sandy soil than in clay soil. This is because the proportions of cations in the exchange complex can be altered more readily in sandy soils. Inherent fertility problems of clay soils are frequently more difficult to cope with than those of sandy soils.

In addition to the nutrients in the exchange complex there are nutrients present in soil organic matter, in soil minerals, and in salts with varying degrees of solubility. The availability to the tree of these nutrients in their various forms is greatly influenced by root environment.

In general, soils in humid regions have been thoroughly leached, and the supply of available nutrients is low. These soils are often acid and such cations as calcium, magnesium, potassium, and sodium have been leached and aluminum and hydrogen ions predominate in the exchange complex. Also, well-leached soils are frequently deficient in other nutrients such as nitrogen, phosphorus, boron, iron, zinc, manganese, copper, and molybdenum.

Not only are many nutrient elements leached from humid-region soils, but, because of the high acidity (low pH), other nutrients, such as phosphorus and molybdenum, are converted to forms that are difficultly available to the tree, nitrification is reduced, and some metals, such as aluminum, copper, and manganese may become so soluble that they prove toxic to the citrus tree. Liming reduces soil acidity (increases the pH), and converts elements such as aluminum, copper, and manganese to less soluble forms. Recommendations for the acid, sandy soils of Florida are to maintain soil between pH 5.5 and 7.0 (Reitz *et al.*, 1972).

In contrast to the acid, sandy, humid-region citrus soils of central Florida are the alkaline, sandy loam-to-clay soils of the arid regions of California and Arizona. Little leaching occurs under conditions of low rainfall and high evaporation. Thus, carbonates, sulfates, and chlorides of sodium, calcium, potassium, and magnesium accumulate. Hence, one of the primary functions of irrigation under these conditions is to leach soluble salts down to depths below the root zone and maintain their concentration at a level low enough to permit good tree growth (see chap.

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4). Under these conditions, the exchange complex in the soil is saturated predominantly with calcium, magnesium, potassium, and sodium. Thus, soils are usually alkaline in reaction. In terms of tree growth, these soils are generally well-supplied with phosphorus, calcium, and potassium. Evidence is accumulating that under some circumstances magnesium is replaced in the exchange complex in the soil by other cations from sources such as fertilizers, manures, soil amendments, and irrigation water, and indications are that magnesium is moved to lower soil depths. If corrective measures are not taken soon, magnesium deficiency in California may become even more prevalent in the future (Embleton and Jones, 1959).

With the exception of nitrogen and possibly potassium, nutrient deficiencies of citrus trees growing on alkaline soils frequently are caused by unavailability rather than by a low total supply of nutrients. Zinc, manganese, iron, and copper under alkaline soil conditions exist in forms which are not readly available to citrus trees.

Physical characteristics of soil, which are discussed in Chapter 4, cannot be divorced from fertility and nutritional problems. Inadequate soil drainage or excessive soil moisture intensifies the iron deficiency of citrus trees growing in alkaline soils.

Knowledge of the physical characteristics of arid-region soils is important in coping with inherent salt problems. Excess salt in a clay soil is very difficult to manage. Not uncommonly, irrigation water in arid regions contains excessively high concentrations of specific salts such as those of sulfur, boron, and chlorine. These salts in excess cause characteristic symptoms to appear on leaves, and premature defoliation may result. When such salts are high in irrigation water, the desirable management is to control irrigation to prevent the salts from accumulating in the soil and to maintain the concentrations of salts in the soil solution as near as possible to that in the irrigation water (see chap. 4). In clay soils with restricted drainage, such control is more difficult than in sandy soils which provide favorable drainage.

Excesses of some of the specific salts may have to be considered in planning a proper nitrogen-fertilization program (Jones *et al.*, 1963). This problem is dealt with in more detail later in this chapter.

FERTILIZER MATERIALS AND SOIL AND PLANT RELATIONS

Certain elements or chemical compounds in fertilizers may have effects on soil and on tree growth that are not related to their nutritional effects within the tree. Certainly, one cannot supply nutrients to a soil without considering that the net effect upon trees is influenced by some degree of competition for those nutrients by soil microorganisms, effect on soil tilth, and other indirect factors. This section considers fertilizers only as they supply nutrients to the trees.

Nitrogen

Among those elements necessary for adequate tree growth, nitrogen is most likely to be found in short supply in the soil. Evidence shows that a shortage of nitrogen in citrus trees is likely to be most critical just prior to and during blossoming, fruit-setting, and "June drop" (Chapman and Parker, 1942). Murcott tangor collapse in Florida appears to be associated with a stress for nitrogen and potassium during the period that the "on crop" of fruit is maturing. Higher rates of nitrogen and potassium than are commonly used on oranges and grapefruit improved Murcott tree condition (Stewart, Wheaton, and Reese, 1968).

Nitrogen is available on the market and in the soil in many forms. The most important sources of nitrogen for citrus production include nitrate or ammoniacal forms or combinations thereof, urea, and natural organic materials. An average analysis of a number of fertilizer materials appears in table 5–1. A knowledge of the properties of these various forms of nitrogen and of transformations of nitrogen in the soil is essential if one is to adequately and efficiently supply nitrogen to citrus trees growing under various environmental conditions throughout the world.

Nitrate Sources.—Nitrate nitrogen is the form most commonly absorbed by citrus trees, but they absorb ammoniacal nitrogen if pH is properly controlled (Smith, 1957; Smith and Reuther, 1954). Nitrate ions move with water in the soil and are not bound to soil particles. However, little evidence exists indicating that leaching of nitrogen need be a serious problem in citrus production, although overuse may result in excessive leaching losses and increases in nitrate in underground waters.

Only a part of the nitrogen applied as fertilizer could be accounted for in the California crop (Chapman, 1951), and only 20.7 per cent in

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the Florida crop (Smith, 1963). Leaching, volatilization, and accumulation probably account for the remainder (Chapman, 1951; Harding, 1954; Volk, 1961). In Florida, 18 ppm of nitrate-nitrogen (80 ppm of nitrate) and 0.67 ppm of ammoniacal-nitrogen were found in underground drainage water from a hillside orchard, compared with 1.05 ppm of nitrate-nitrogen and 0.40 ppm of ammoniacal-nitrogen from an unfertilized area (Wander, 1951). Bingham, Davis, and Shade (1971) reported that the nitrate concentration in the effluent from a 960-acre watershed planted to citrus in southern California averaged 50 to 60 ppm over a three-year period when trees were about seven to ten years old. These nitrate losses were from 40 to 50 per cent of the 130 pounds of nitrogen per acre applied during this period. Data of Pratt, Jones, and Hunsaker (1972) from the long-term fertilizer experiment with navel oranges at the University of California Citrus Research Center show that the nitrate concentration in the soil solution from 10 to 100 feet deep averaged 97 ppm for the 50 pounds of nitrogen per acre treatment and 207 ppm for the 550-pound treatment. In the 350-pound treatment there were 92 ppm at the 10- to 66-foot depth and 198 ppm for the 67- to 100-foot depth. Two hundred pounds of nitrogen per acre from manure resulted in 110 ppm of nitrate in the 10- to 100-foot depth. These measurements were made seven years after differential treatments were terminated, during which time all treatments received 150 pounds of nitrogen per acre from ammonium nitrate.

In many of the cases just discussed, nitrogen rates used were higher than is now known to be necessary to maintain production. Under excessive nitrogen regimes, losses are unavoidable. Depending on soil and climate, after termination of a high or excessive nitrogen rate program, trees may show nitrogen deficiency symptoms promptly (Reitz and Hunziker, 1961; Reitz and Koo, 1960; Stewart, Leonard, and Wander, 1961) or fail to show symptoms of nitrogen deficiency until after many years (Jones *et al.*, 1959). For high-rate programs, nitrogen timing may be inconsequential (Reuther and Smith, 1954; Reuther *et al.*, 1957). Under lower application rates, nitrogen is used more efficiently, and changes in nitrogen timing and rate are more promptly reflected in tree condition (Jones and Embleton, 1959; Smith, Scudder, and Hrnciar, 1969).

Young Valencia orange trees on rough lemon rootstock growing in a silica-gravel culture absorbed both nitrate and ammoniacal nitrogen with extreme rapidity from a nutrient solution poured through the gravel after a period of nitrogen starvation (Bitcover and Wander, 1950). Jones, Van Horn, and Finch (1945) and Hilgeman, Smith, and Draper (1940) showed that, in Arizona, applications of nitrogen to grapefruit trees already high in nitrogen did not increase leaf nitrogen concentration; but the leaf nitrogen concentration was readily increased in trees that were initially low in nitrogen.

Chapman and Parker (1942) showed that young trees amply supplied with nitrate nitrogen absorbed additional nitrates from nutrient solutions in proportion to temperatures of the solutions bathing the roots. In winter, less nitrate nitrogen was absorbed than in summer. Roy and Gardner (1945) made similar observations from orange trees growing in outdoor sand cultures, and they showed that the amount of nitrogen uptake was reduced less in winter than was the uptake of phosphorus, potassium, calcium, and magnesium. Data of Naudé (1958) showed that young Eureka lemon plants on various rootstocks produced a greater dry plant weight and absorbed more total nitrogen from nutrient solutions with a root temperature of 75° F than at either 65° F or 90° F. However, field evidence shows that even in winter, when soil temperatures are low, citrus trees will, if initially low in nitrogen, absorb applied nitrate nitrogen rapidly and in quantities adequate to supply the trees' needs (Jones *et al.*, 1945; Leonard and Stewart, 1960).

Under most orchard conditions, if nitrogen is rapidly passed through the root zone, it appears that the tree will absorb enough nitrogen to supply it for many months. The amount passing through the root zone probably exceeds the tree's immediate requirements suggesting that with an efficient nitrogen-fertilizer program, little leaching of nitrogen occurs.

Reuther and Smith (1954) suggested that low nitrogen efficiency in Florida citrus groves is due to some factor other than leaching; however, the rapid mobility of nitrate nitrogen in the soil cannot be ruled out completely as an influential factor in citrus production. Theoretically, nitrate nitrogen should be more rapidly available to the tree than ammoniacal nitrogen, because it is soluble in the soil solution and can readily be transported to the root zone, whereas ammoniacal nitrogen may be adsorbed near the soil surface.

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Table 5–1
AVERAGE ANALYSIS OF FERTILIZER MATERIALS

Fertilizer Materials	Chemical Formulae	Composition (Per Cent)					Equivalent Acidity or Basicity in Pounds of Calcium Carbonate‡	
		Total Nitrogen (N)	Available Phosphorus° (P)	Water-Soluble Potassium† (K)	Combined Calcium (Ca)	Combined Sulfur (S)	Acid	Base
Nitrogen materials:								
Ammonium nitrate	NH_4NO_3	33.5	.....	.....	.....	.....	62	.....
(Mono) Ammonium phosphate	$NH_4H_2PO_4$	11	21	.....	1.4	2.6	58	.....
Ammonium phosphate sulfate	$NH_4H_2PO_4$ $(NH_4)_2SO_4$	13	17	.....	.....	7	69	.....
Ammonium phosphate sulfate	40% $NH_4H_2PO_4$ 60% $(NH_4)_2SO_4$	16	9	.....	0.6	15.4	88	.....
Ammonium phosphate nitrate§	.....	24	9	.....	.....	.....	60	.....
Ammonium phosphate nitrate§	.....	27	6	.....	.....	.....	60	.....
Diammonium phosphate	$(NH_4)_2HPO_4$	21	23	.....	.....	.....	75	.....
Ammoniated single superphosphate¶	.....	3–4	7–8	.....	15.0	12	4–7	.....
Ammoniated triple superphosphate¶	.....	4–6	18–20	.....	12.9	1	11–14	.....
Nitric phosphates¶	.....	14–20	6–9	.....	8–10	0–4	15–29	.....
Amonium chloride	NH_4Cl	25	.....	.....	.....	.....	140	.....
Ammonium sulfate	$(NH_4)_2SO_4$	20–21	.....	.....	.....	24	110	.....
Anhydrous ammonia	NH_3	82	.....	.....	.....	.....	147	.....
Aqua ammonia	NH_4OH	20	.....	.....	.....	.....	36	.....
Ammonia-ammonium nitrate solution	NH_4NO_3 NH_4OH	40	.....	.....	.....	.....	80	.....

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Calcium-ammonium nitrate solution	11.6% $Ca(NO_3)_2$, 5.4% NH_4NO_3	17	.....	.....	8.8	.....	9	.....
Calcium nitrate	$Ca(NO_3)_2$	15.5	.....	.....	21	.....	.....	20
Calcium cyanamide	$CaCN_2$	20–22	.....	.....	37	.....	.....	63
Sodium nitrate	$NaNO_3$	16	.....	.....	.....	.....	.....	29
Urea	$CO(NH_2)_2$	45–46	.....	.....	.....	.....	71	.....
Urea-formaldehyde‖	.....	38	.....	.....	.....	.....	.....	.....
Urea-ammonium nitrate solution	35.4% $CO(NH_2)_2$, 44.3% NH_4NO_3	32	.....	.....	.....	.....	57	.....
Phosphate materials:								
Superphosphate single	50% $CaSO_4$, 30% $CaH_4(PO_4)_2$••	.....	8–9	.....	18–21	12	neutral	.....
Superphosphate double or triple	$CaH_4(PO_4)_2$••	.....	18–20	.....	12–14	0–1	neutral	.....
Liquid phosphoric acid	H_3PO_4	.....	23–24	.....	.....	.....	110	.....
Potash materials:								
Potassium chloride	KCl	.....	.....	51	0.3	.....	neutral	.....
Nitrate of soda-potash	$NaNO_3$•KNO_3	15	.....	12	.....	.....	.....	25
Potassium nitrate	KNO_3	13	.....	37	.....	.....	.....	23
Potassium sulfate	K_2SO_4	.....	.....	47	.....	18	neutral	.....
Sulfate of potash magnesia	K_2SO_4•$2MgSO_4$	.....	.....	22	1	15	neutral	.....

Source: Adapted from Shaw (1965).
• To convert per cent of phosphorus (P) to per cent of phosphoric acid (P_2O_5) multiple by 2.3.
† To convert per cent of potassium (K) to per cent of potash (K_2O) multiply by 1.2.
‡ Equivalent per 100 lbs of each material.
§ In some areas, the term ammonium nitrate phosphate is used.
¶ The ammoniation products.
‖ Also known as urea-form; these materials are reaction products of urea and formaldehyde.
•• Some workers use the formula $Ca(H_2PO_4)_2$•H_2O, which has the same chemical significance.

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Most evidence seems to substantiate this. In the Salt River Valley in Arizona, Hilgeman *et al.* (1940) and Hilgeman (1941) found that nitrogen was taken up by grapefruit trees most rapidly from calcium nitrate, followed in order by urea, ammonium sulfate, and manure. Van der Merwe (1949), in the Rustenberg area of South Africa, observed growth of citrus to start from two to three weeks earlier with calcium nitrate than with ammonium sulfate, and attributed this to earlier absorption of nitrogen from calcium nitrate. However, orchard trees growing in the acid sands of Florida and fertilized in December had a higher leaf-nitrogen concentration in March if ammonium sulfate was used than if calcium or sodium nitrates were applied (Leonard and Stewart, 1960).

The movement of nitrate nitrogen and other soluble salts with water in soil is also important as it relates to type of culture and irrigation in the orchard. Harding (1954) found in excess of 800 pounds of nitrogen per acre accumulated in the upper 6 inches of the interfurrow ridges in California orchards. Nitrate ion always predominated, usually accounting for about two-thirds of total anions. In many orchards, enough nitrogen accumulated to supply the trees for many years if it was properly distributed in the root zone. If these accumulated salts were all moved into the root zone at once, serious damage could result. Certainly, nitrogen from the applied fertilizer was no small factor in this accumulation. Soluble salts move upward into interfurrow ridges as a result of capillary conduction and accumulate there as a result of evaporation. The magnitude of this conduction and accumulation is influenced by the rate of water evaporation from soil, amount and type of irrigation, rainfall, soil texture and profile characteristics, type and shape of furrow, degree of stirring of soil, method of applying fertilizers, and the amount of soluble salts in the soil.

In planning an efficient nitrogen-fertilizer program, steps should be taken to prevent excessive use or accumulation of nitrates and other soluble salts in the soil.

Nitrate of potassium from Chilean deposits was used frequently for citrus growing on acid soils. This fertilizer sometimes contained sufficient perchlorate impurities to cause a distinctive orange or yellow tipping of leaves (Stewart and Leonard, 1953); synthetic nitrate, however, does not produce the toxicity (Stewart and Leonard, 1958). Although not recommended, Chilean sodium nitrate has been used experimentally on neutral to slightly alkaline soils in California, and the same yellow tipping developed on leaves. Chilean sodium nitrate was very commonly used in Florida, and when used as a sole source of nitrogen, slight yellow tipping was occasionally seen. Improved refining and processing techniques, though, have nearly eliminated this difficulty (Reese, 1967). High rates of nitrate of soda may also cause sodium toxicity (Smith, 1962*b*).

Ammoniacal Sources.—Nitrogen in ammoniacal form, such as ammonium sulfate, is soluble in water, but does not move readily through most soils with soil water. The ammonium ion is adsorbed on the exchange complex and held until displaced by another cation or until converted into nitrate by microorganisms in the soil. The lower the cation-exchange capacity of the soil, the more readily will the ammonium ion move through the soil with water. One of the authors observed ammonium ion at a depth of 10 feet in a grapefruit orchard on the Yuma Mesa in Arizona. This orchard was fertilized with ammonium sulfate, and in this alkaline sandy soil of very low exchange capacity the ammonium ion was presumably moved rapidly through the soil in the large amounts of irrigation water that were applied. The population of nitrifying organisms may be low in the lower depths of soil.

However, in most soils, ammonium ions are adsorbed by soil at the first point of contact. Under optimum conditions, a major portion of ammoniacal nitrogen in soil may be nitrified to nitrate nitrogen in two to three weeks (Broadbent, Tyler, and Hill, 1957). Soil conditions in citrus orchards, however, are not always optimum for nitrification. Generally, nitrification does not take place if soil temperature is freezing or below, but it begins at about 35° F to 40° F and slowly increases to the most favorable temperature of 80° F to 90° F. At a temperature of 125° F, nitrification practically ceases (Buckman and Brady, 1969). Sabey *et al.* (1956) studied temperature effects upon nitrification in three soils when ammonium ion was not limiting and found that nitrification rates were about 50 per cent, 25 per cent, and 6 per cent as rapid at 68° F, 59° F, and 46° F, respectively, as at 77° F. Frederick (1956) showed that if pH and soil moisture were favorable, the two surface soils with which he worked nitrified all of the 180 ppm (equivalent to about 720 pounds per acre-foot of soil) of added am-

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monium ion in about four weeks at 59° F; at higher temperatures, the ammonium nitrified in shorter periods of time.

Bliss (1944) studied soil temperatures near the center of a Valencia orange orchard near Anaheim, California. Temperatures were recorded at various depths for an area near the southeast side of a tree that on clear days was normally exposed to sun from early morning to mid-afternoon. The area was kept free of weeds and cover crops during temperature readings from February, 1939, to July, 1943, and was flood-irrigated during the summer. Temperatures were also recorded for a shaded area near the trunk of the tree. The orchard was about ten miles from the coast and subject to cool ocean breezes from the southwest and occasional hot, dry winds arising in the interior desert regions to the northeast. Select air temperatures and soil temperatures at the 3-inch depth are shown in figure 5–1. Since the ammonium ion is adsorbed by surface soil particles, temperatures in that area of the soil are important in converting the immobile ammonium form to the mobile nitrate form that will move down with water. Data in figure 5–1 show that weekly mean soil temperatures at the 3-inch depth under the shade of the tree followed very closely those of weekly mean air temperatures, but at the same depth, when the soil was exposed to sunlight, the mean temperatures were considerably higher. During the critical period just before and during bloom, weekly mean soil temperatures at the 3-inch depth ranged from about 53° F to about 64° F. Weekly means are presented in figure 5–1, and it must be realized that there were daily fluctuations around the means. For example, during January 4 to 5, 1941, soil temperatures at the 3-inch depth in the unshaded area ranged from about 44° F to 53° F, while air temperatures ranged from about 38° F to about 57° F. During the period August 9 to 10, 1940, soil temperatures at the 3-inch depth in the unshaded area ranged from about 70° F to about 93° F, while air temperatures ranged from about 57° F to about 92° F. Also, it must be realized that in the unshaded area, the temperatures at soil surface were warmer after exposure to sun than soil at the 3-inch depth. At night, after heat was radiated from the soil, temperatures at the surface were cooler than at the 3-inch depth.

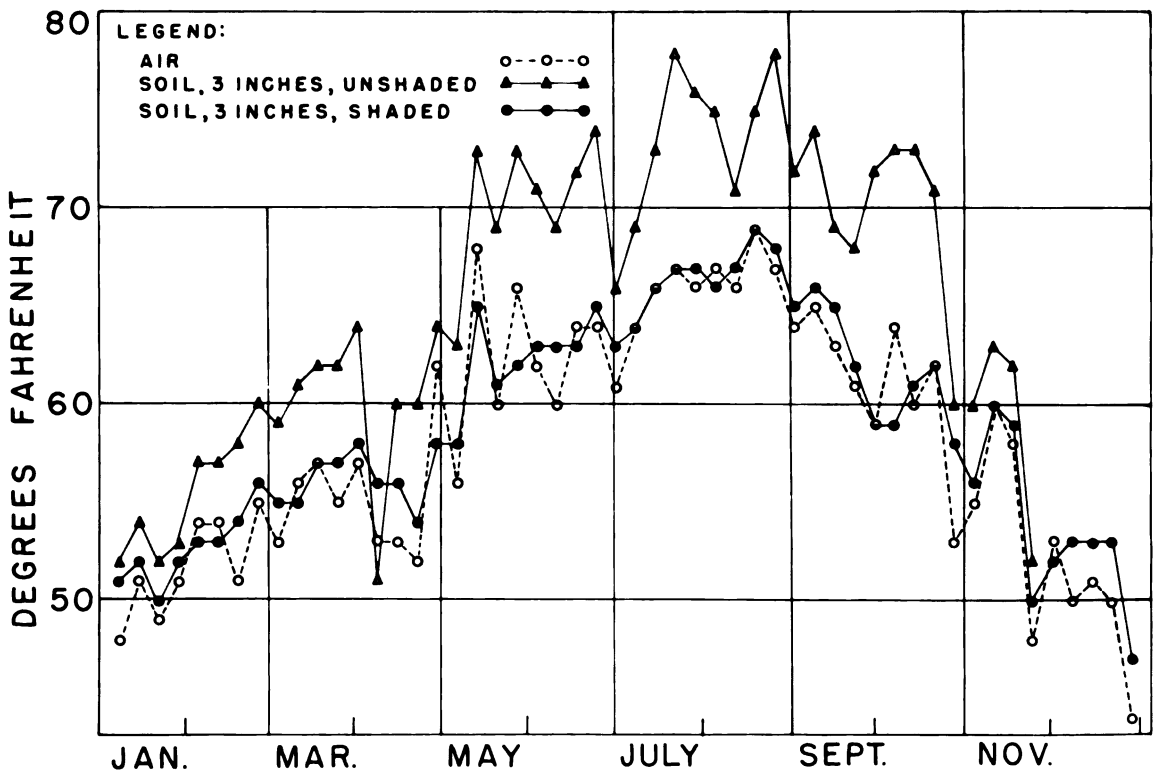

Fig. 5–1. Weekly mean temperatures of soil at 3-inch depth and air in a Valencia orange orchard at Anaheim, California, in 1941. (Adapted from Bliss, 1944.)

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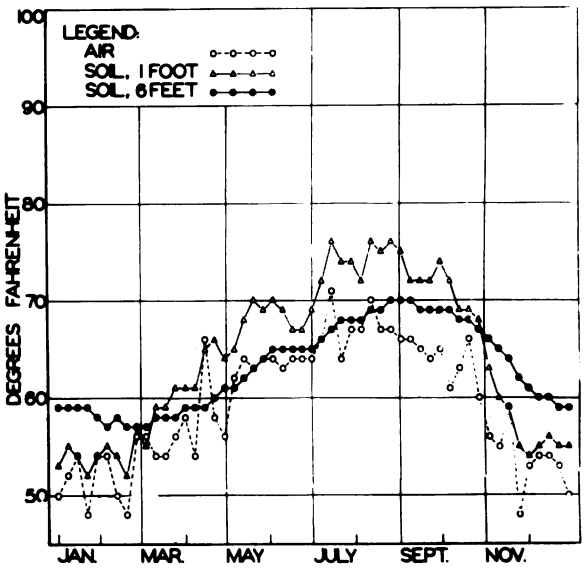

Fig. 5–2. Weekly mean temperatures of soil and air in a date garden at Indio, California, in 1936. (From Bliss, 1944.)

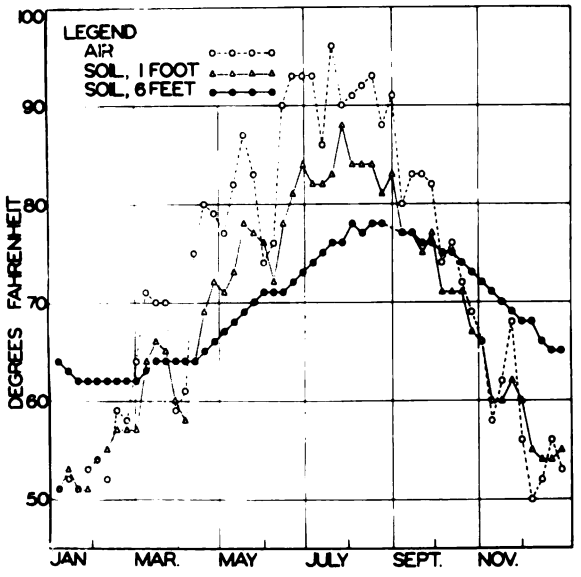

Fig. 5–3. Weekly mean temperatures of soil and air in an unshaded area of a Valencia orchard near Anaheim, California, in 1940. From Bliss, 1944.)

Figures 5–2 and 5–3 show data of Bliss (1944) comparing temperatures in the Anaheim, California orange orchard with temperatures in a date garden near Indio, California. From these data, it may be deduced that the surface layer of a desert soil exposed to the sun may reach temperatures at which nitrifying organisms are destroyed. In Anaheim (near the Pacific Coast, where ocean breezes are influential) mean air temperatures were lower than mean soil temperatures at one foot during the February-to-April period, while in the desert area mean air temperatures were about equal to or higher than mean soil temperatures during the same period.

Many factors influence soil temperature (Buckman and Brady, 1969). Shading from sun results in lower soil temperature. Dark-colored soils adsorb more energy from the sun than light-colored soils. The nearer the angle of incidence of the sun's rays to perpendicular, the greater will be the energy absorbed. Bare soils warm up more quickly and cool off more rapidly than those covered with vegetation or mulches. The greater the evaporation rate, the greater the cooling effect on the soil. The greater the water content in the soil, the slower the rate of temperature change. A sandy soil is considered to be a warmer soil than a clay soil.

Soil temperature data suggest that, under California conditions, nitrification of ammoniacal fertilizers is rapid enough to satisfy the trees' needs if the material is applied before the end of February, and if there is adequate rainfall or irrigation to carry the nitrate formed into the root zone. Similar soil temperatures exist in other citrus districts of the world. (See chap. 9.)

Soil pH has a strong influence on the nitrification rate. Aldrich, Parker, and Chapman (1945) demonstrated that continued use of ammonium sulfate in a citrus orchard in California resulted in a very acid soil in which large quantities of ammonium ion accumulated in the exchange complex, presumably because nitrification was drastically reduced at the low soil pH. Frederick (1956) showed that by adjusting soil pH from slightly above 7.0 to 6.2 and 5.0, the nitrification rate was progressively and markedly reduced. However, at pH 5.0, and at a favorable temperature, about half of the added ammoniacal nitrogen was nitrified in four weeks. Below pH 4 nitrification practically ceases.

Waterlogging reduces soil aeration and thereby retards nitrification. At the other extreme, nitrification in dry soils is retarded by lack of moisture. The optimum moisture content is about 50 to 70 per cent of field capacity. Conceivably, soil moisture in exposed surface soil in a citrus orchard could at times be low enough to retard nitrification. However, conditions resulting in severe drying of the surface soil would probably

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result in a high nitrification rate during drying. Excess salt or high soil ammonia (NH_3) at pH values of about 7.6 or higher may also reduce nitrification (Broadbent, *et al.*, 1957).

Even though nitrification of ammoniacal nitrogen in soil is influenced by many factors, it appears that, in citrus production, the difference in availability rates of nitrate and ammoniacal nitrogen forms is not important. One may reason from available information that, in subtropical regions, nitrogen applied in nitrate form in early spring usually will be available to the tree about three weeks sooner than nitrogen applied in ammoniacal form. If one applies nitrogen six weeks or more before bloom, then the difference in nitrogen availability rate from nitrate and ammoniacal forms is normally of little practical consequence, if there is rainfall or irrigation to carry the nitrogen into soil.

If the application of ammoniacal nitrogen is immediately followed by irrigation or rain, the nitrogen will not move through the soil with the water, but will be held by the surface soil. If the surface soil does not become too dry after fertilizer application, an appreciable amount of ammoniacal nitrogen will be nitrified in two or three weeks. After nitrification, there must be adequate rain or irrigation to carry the nitrate into the root zone. If one is dependent upon furrow irrigation to carry the nitrate into the root zone, the fertilizer should be applied in the furrow bottoms.

Urea Source.—Urea is usually considered an ammoniacal nitrogen source, but since it is not in ammoniacal form when applied, it is discussed separately. Except for that present in applied manures, the urea used in fertilizers is a synthetic product. It is an organic material and soluble in water. In urea's initial form, its rate of movement through soil with soil water is somewhat less than that of nitrate nitrogen, but appreciably more than that of ammoniacal nitrogen (Broadbent, Hill, and Tyler, 1958; Chin and Kroontje, 1962).

Urea is hydrolyzed in soil to an ammoniacal form of nitrogen, and transformations from this point on are not different from those in other ammoniacal forms. The reaction rate of chemical hydrolysis is very slow; biochemical hydrolysis of urea is related to activities of soil microorganisms (Chin and Kroontje, 1963). Under favorable conditions, more than half of the urea applied to a soil may be hydrolyzed in twenty-four hours. If the soil is dry or if soil temperatures are low, or both, hydrolysis proceeds more slowly; its nitrogen product is the immobile ammonium ion. Urea can be moved into the root zone and absorbed by roots as urea if adequate rainfall or irrigation occurs before hydrolysis; if not absorbed, however, hydrolysis to ammoniacal nitrogen occurs, and nitrification then takes place in the root zone.

Although not a serious problem, "yellow tip" of citrus leaves can occur from soil applications of urea containing appreciable biuret, an impurity formed in the manufacturing processes. In mild form, this symptom may be confused with either boron or perchlorate toxicity. Urea containing over 2.5 per cent of biuret should not be used in citrus orchards in California (Jones, Embleton, and Goodall, 1955). Similar recommendations have been made in Japan (Iwasaki and Shichijo, 1962).

Urea is also used as an effective source of nitrogen for foliar fertilization of citrus. All or part of the nitrogen needs of a citrus tree may be supplied by foliage sprays. Impey and Jones (1960), Jones and Parker (1949*a*), and Jones and Steinacker (1953) showed that nitrogen from urea was readily absorbed by orange leaves. Successful use of urea foliage sprays on citrus was not achieved until it was learned that biuret and not urea *per se*, was the cause of "yellow tip" of the leaves (Jones, 1954; Jones and Embleton, 1954*b*). Typical "yellow tip" is illustrated in figure 5–4. A biuret tolerance level in urea to be used for foliar sprays was established by Jones *et al.* (1955). With this information available, fertilizer manufacturers undertook research to develop urea containing less than 0.25 per cent of biuret as an impurity, which was prescribed in the recommended tolerances for citrus. Today, urea with less than 0.25 per cent of biuret is readily available on the United States market and is widely used in California as a foliar spray on citrus. The absorption of nitrogen by the leaf is generally proportional to the concentration of the urea spray, and the aim is to use as high a concentration as possible without injury. The recommended concentration is 7-½ pounds of urea, containing less than 0.25 per cent of biuret, per 100 gallons of spray solution at the rate of about 700 gallons per acre; but preliminary evidence of the authors indicates that in desert areas higher concentrations may be safely used. In Japan, frequent 0.5 per cent (4.2 pounds per 100 gallons) sprays with crystalline urea containing not more than 0.1 per cent of biuret were suggested for spring application (Iwasaki and Shichijo, 1962).

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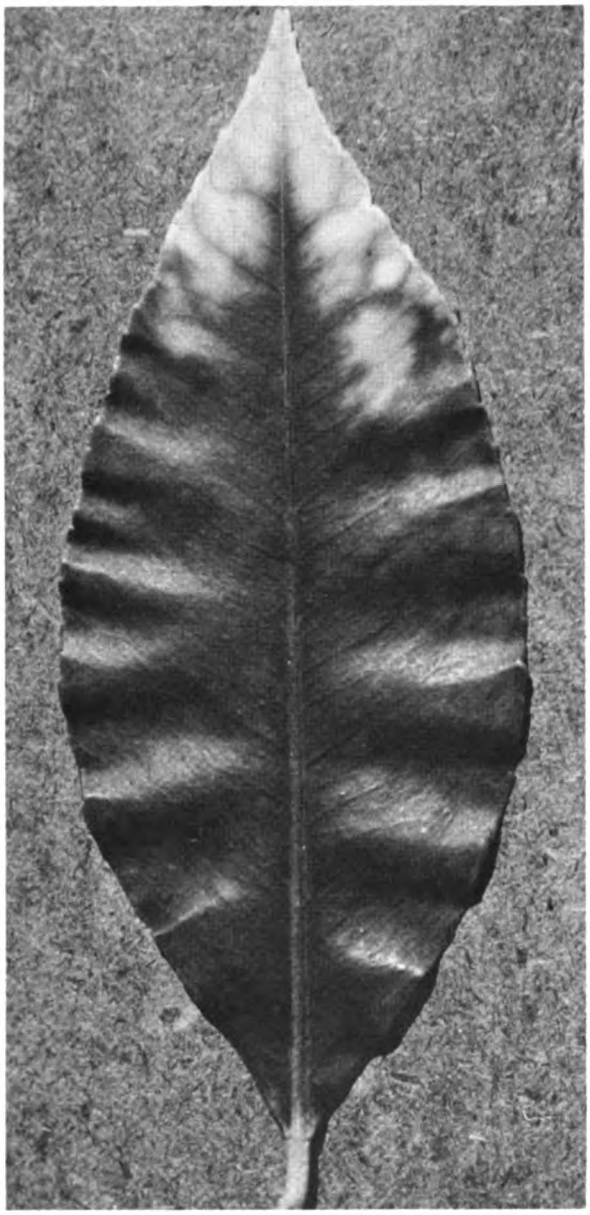

Fig. 5–4. Typical "yellow tip" on a lemon leaf that resulted from biuret impurity in urea.

Chen (1954) reported that, with equal amounts of nitrogen applied, grapefruit trees receiving foliar urea sprays had a slightly lower nitrogen level in leaves than those receiving soil applications.

Urea is compatible with micronutrient and with most pesticide spray materials.

Natural Organic Materials.—Even though inorganic fertilizer materials increasingly constitute the major nitrogen source for citrus, natural organic materials, such as animal manures, plant residues, and sludges, are still important nitrogen sources. They are probably of greatest importance as soil amendments (see discussion, p. 148). For the most part, nitrogen in organic materials is not in a form available to trees until the materials have decomposed. Upon decomposition, inorganic forms of nitrogen are formed, such as ammonium and nitrate salts, and from then on they behave the same as these forms from synthetic sources.

The decomposition rate of organic materials added to soil depends upon many factors, including the nature of the material, soil temperature, moisture supply, soil aeration, microorganisms present, soil pH, and availability of supplemental inorganic nutrients.

During decomposition of organic materials in soil, nitrogen may be released gradually over a long period of time. Materials that are high in nitrogen (low carbon:nitrogen ratio), or which are supplied with supplemental sources of available nitrogen, decompose somewhat more rapidly than materials that are low in nitrogen (high carbon:nitrogen ratio). In the decomposition process, the carbon present is oxidized by microorganisms to carbon dioxide, and excess nitrogen is released as ammonia. When low nitrogen organic residues are applied to the soil, several months may elapse before the nitrogen content in the remaining residue is present in excess of the microbial requirements.

If an organic material low in nitrogen (such as cereal straw) is added to a soil, the soil microorganisms compete with the tree for the available soil nitrogen. Even materials which have an intermediate amount of nitrogen may, when added to a soil, result in a reduction in soil nitrates for a period of time. Waksman (1952) presented data showing that when wheat straw (0.5 per cent nitrogen) was added to soil, the nitrogen released over a 180-day period was considerably less than the release from the control soil to which no organic material was added. When farmyard manure, which has an intermediate carbon:nitrogen ratio (about 1 per cent nitrogen), was added to soil, the nitrogen released was less than that of the control soil for fifty days. After fifty days, the rate of release increased over that of the control soil. If an organic material contains about 1.5 to 1.8 per cent of nitrogen or more, the microorganisms utilize little of the soil supply and will, upon further decomposition, release excess nitrogen as ammonia.

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These fluctuations in available nitrogen in the soil as a result of additions of organic materials have many important implications in citrus production. Since organic materials low in nitrogen added to the soil result in a reduction of nitrate nitrogen for a period of time, such materials should not be added in spring when the nitrogen supply is so critical to the tree. In California, manure applied in the spring resulted in a lower yield of Washington navel oranges than when applied in the fall (Parker and Jones, 1951).

When green manure crops are worked into the soil in the spring, additional nitrogen is needed to satisfy the needs of the microorganisms that decompose the green manure. Animal manures should be applied in the fall so that their decomposition will not limit nitrogen available to the trees in the critical spring period.

A high nitrogen level in orange and grapefruit trees in the summer adversely affects quality of fruit for fresh market (see Fruit Size and Quality, p. 165). When organic materials are used, nitrogen is made available to the trees throughout the year, even when the materials are applied only in late summer or fall. This results in difficulty in controlling the nitrogen level in trees during the summer period.

The amounts of nitrogen in various organic materials must be considered in planning a fertilizer program. Too frequently, growers fail to consider the amounts of nitrogen that are added from these sources. Information prepared by the University of California Farm Advisor's Office of Los Angeles County on common manures that were available in that area is summarized in table 5–2. Table 5–3 presents average analyses of organic materials for nitrogen and other constituents.

Nitrogen Losses.—There are many paths along which nitrogen can be lost from the soil. Leaching has already been discussed. There are also losses of several forms of nitrogen in the gaseous state. When the surface layer of soil, or a portion thereof, is alkaline, there is a possibility of loss from ammoniacal fertilizers or fertilizers that yield ammoniacal nitrogen. Martin and Chapman (1951) showed that there were losses of up to 51 per cent of the added nitrogen from surface-applied ammonium hydroxide. Ammonium hydroxide applications temporarily raised

Table 5–2
NITROGEN IN POULTRY AND ANIMAL MANURES

Types of Manure	Average and Range†	Nitrogen* (N) (Per cent)	Weight (Lb/Ft³)	Elemental N Per Ft³ Manure (Pounds)	Elemental N Per Ton Manure (Pounds)
Poultry layers, dry droppings	average	3.22	22	0.70	64
	range	(2.5–4.6)	(13–30)	(0.5–0.8)	(50–92)
Poultry layers, wet droppings	average	1.37	40	0.55	27
	range	(0.6–2.3)	(24–60)	(0.3–0.7)	(12–46)
Steer, dry droppings	average	2.40	25	0.59	48
	range	(1.9–3.0)	(18–34)	(0.4–0.7)	(38–60)
Steer, from wet feedlots‡	average	0.65	50	0.34	13
	range	(0.56–0.75)	(40–62)	(0.2–0.4)	(11–15)
Dairy, from dry corrals	average	1.79	21	0.37	36
	range	(1.3–2.4)	(16–32)	(0.3–0.5)	(26–48)
Dairy, from wet corrals	average	0.49	54	0.26	10
	range	(0.3–0.7)	(42–70)	(0.2–0.3)	(6–14)

Source: Beutel *et al.* (1958).

*The per cent of nitrogen was determined on a "wet" basis; that is, just as the manure is in corral or under poultry cages. This gives a lower but more realistic percentage of nitrogen than the "oven-dry" basis often reported by laboratories.

† Range shows the amount of variation between different samples of the same type of manure.

‡ "Wet" from rains.

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Table 5–3
AVERAGE ANALYSES OF ORGANIC MATERIALS

Type of Material	Per Cent*				Cubic Feet Per Ton
	Nitrogen (N)	Phosphorus† (P)	Potassium‡ (K)	Organic Matter	
Bulky organic:					
Goat manure	2.77	0.78	2.39	60	70
Dairy manure	0.7	0.13	0.54	30	55
Steer manure	2.0	0.24	1.59	60	70
Horse manure	0.7	0.15	0.43	60	75
Hog manure	1.0	0.33	0.71	30	60
Sheep manure	2.0	0.44	2.08	60	70
Rabbit manure	2.0	0.58	1.00	50	70
Poultry droppings	4.0	1.40	1.58	74	55
Poultry manure	1.6	0.55	0.75	50	50
Seaweed (kelp)	0.2	0.04	0.50	80	....
Alfalfa hay	2.5	0.22	1.74	85	....
Alfalfa straw	1.5	0.13	1.25	82	....
Bean straw	1.2	0.11	1.04	82	....
Grain straw	0.6	0.09	0.91	80	....
Cotton gin trash	0.73	0.08	0.99	80	....
Winery pomace (dried)	1.0 to 2.0	0.65	0.42 to 0.83	80	....
Olive pomace	1.2	0.35	0.42	80	....
Organic concentrates:					
Dried blood	13.0	0.65	....	80	....
Fish meal	10.4	2.57	....	80	....
Septic sludge (digested)	2.0	1.31	....	50	....
Nitroganic	6.5	1.48	0.25	80	....
Tankage	7.0	3.75	1.25	80	....
Cottonseed meal	6.5	1.31	1.25	80	....
Bat guano§	13.0	2.18	1.66	30	....
Castor pomace	6.0	1.09 to 1.31	0.42	80	....

Source: Adapted from Shaw (1965).

* All organic materials should be purchased on the basis of actual analysis. There is a wide variation in value due to moisture content, type of storage, and other conditions. The tabulated values are averages taken from official literature.

† To convert per cent of phosphorus (P) to per cent of phosphoric acid (P_2O_5) multiply by 2.3.

‡ To convert per cent of potassium (K) to per cent of potash (K_2O) multiply by 1.2.

§ Bat guano varies widely, due to conditions under which it is taken from caves. Recent deposits are high in nitrogen (N), often 8 to 13 per cent of N, 1.7 to 2.2 per cent of P, and 1.66 per cent of K. Older deposits run 1 to 4 per cent of N and 4.4 to 8.8 per cent of P, with very little K content. These percentage figures are therefore only comparative.

the surface pH of acid soils to the alkaline range, and nitrogen was lost as ammonia gas. Appreciable ammonia loss occurred only when there was a simultaneous water loss from the soil surface.

Ernst and Massey (1960) showed that volatilization of ammonia formed from surface urea applications, applied at a rate equivalent to 100 pounds of nitrogen per acre, was appreciably and progressively increased by raising the soil pH from 6.0 to 6.5, 7.0, and 7.5. They also found that volatilization of ammonia was progressively increased by raising the temperature from 45° F to 60° F, 75° F, and 90° F. These same investigators showed that substantially more ammonia was lost from the soil when exposed to air ranging from 50 to 55 or 85 to 90 per cent relative humidity than to air of 0 or 100 per cent relative humidity.

Volk (1959) showed that surface applications of urea, at an equivalent rate of 100 pounds of nitrogen per acre, to acid Florida soils with low-cation-exchange capacities resulted in nitrogen losses of from 17 to 59 per cent in seven days, while losses from ammonium sulfate were less than 1 per cent. Losses were appreciably less from clay soils where more exchange sites were available to adsorb the ammonium ion. Presumably, the loss occurred from urea because of

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a temporary increase in the pH of the soil's surface, while ammonium sulfate applications did not increase the soil pH.

Volk (1966) reported that on a soil under field conditions with an air-dry surface having a pH of 5.4 to 6.0, over 80 per cent of the applied prilled urea did not hydrolyze within fourteen days; from 42 to 72 per cent persisted where the soil surface was only temporarily moist from recent tillage or irrigation, even though heavy dews formed nightly. When a high water table kept an exposed surface continuously moist, urea completely hydrolyzed within seven days with 65 per cent of the applied nitrogen not accounted for as ammonium, and assumed largely lost as ammonia gas.

In the decomposition of manures, ammonia is an intermediate product and can escape into the air. On comparing manure and inorganic sources of nitrogen in tilled and nontilled citrus and avocado orchards, it was shown that pound-for-pound the nitrogen in manure was nearly as efficient as that from inorganic sources if the manure was worked into the soil. However, when manure was applied as a mulch in nontilled orchards, it was not as efficient as the inorganic-nitrogen sources in supplying nitrogen to the trees (Embleton and Jones, 1955; Harding, Embleton, and Jones, 1963). Presumably, the manure was less efficient because of ammonia loss during decomposition on top of the soil.

Of the common paths of nitrogen loss from soil to the atmosphere discussed thus far, all may be of importance in citrus orchards where certain combinations of conditions exist. However, all of them have general conditions in common. They are associated with the ammoniacal form of nitrogen, they occur at or very near the soil surface, and they are strongly increased by high temperatures. Such losses can be drastically reduced or eliminated if fertilizers containing ammoniacal nitrogen, or forms that are converted to ammoniacal nitrogen, are worked into the soil or carried into the soil by rainfall or irrigation immediately after application (Harding *et al.*, 1963). Losses from winter or early spring applications, when temperatures are low, are considerably less than from summer applications.

There is still another path through which nitrogen may be lost from the soil to the atmosphere. Carter and Allison (1961) showed that applications of increasing rates of ammonium sulfate to acid soils resulted in increasing rates of nitrogen loss in the gaseous states other than that of ammonia. They postulated that the increased salt concentration reduced nitrification and that some of the intermediate products in the conversion of ammonium to nitrate, such as oxides of nitrogen, or even nitrogen gas, were lost to the atmosphere. This implies that, if conditions are such that only part of the steps in the nitrification process are completed, intermediate products accumulate in the soil and may be lost to the atmosphere. Such conditions could exist in a citrus orchard if ammonium sulfate were applied on the surface of the soil in a narrow band.

Nitrogen losses to the atmosphere can also occur as the result of biological denitrification, which is the enzymatic reduction of nitrate and nitrite to volatile gases, ususally nitrous oxide or molecular nitrogen or both. Conditions favoring this process are low concentrations of oxygen in soil, which can be induced by waterlogging soils, warm soils, and the presence of readily decomposable organic matter. In an excellent review article on denitrification, Broadbent and Clark (1965) point out that temporary anaerobism (depletion of oxygen) is a feature of nearly all soils, whether it results from saturation during or after rainfall or irrigation, or from incorporation of crop residues which impose a heavy oxygen demand. They further point out that small pores in soil may be filled with water and are particularly prone to the development of anaerobic conditions, even though the larger pores are filled with air. Investigations have indicated that little nitrogen loss occurs if the moisture content is less than 60 per cent of the water-holding capacity. The amount of loss that occurs in the field by this process is not known, but estimates are in the range of 10 to 15 per cent of applied nitrogen.

It appears that during the summer when soils are warm, temporary conditions would exist in citrus orchards that would be favorable for denitrification. Pratt *et al.* (1972), in a field experiment at the University of California Citrus Research Center, estimated that up to 43 per cent of the added nitrogen was lost by denitrification at the very high nitrogen rates; at nominal nitrogen rates estimates indicated that very little denitrification occurred.

Broadbent and Nakashima (1967), using tracer nitrogen, showed that a substantial amount of fertilizer nitrogen can be converted into organic forms which resist microbial attack and become progressively less available to crops as a function of time. Although such nitrogen is not lost from the soil, it is not readily available to plants.

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Some nitrogen loss occurs when ammonia is applied in alkaline irrigation water. Chapman (1944) concluded that factors of chief importance in determining such losses are soil permeability, temperature, and agitation of water in the basin or furrow. The longer ammonia-containing water stands on the surface of soil, the higher the water temperature, and the greater the agitation, the greater will be the loss. Chapman estimated that under most conditions losses of this nature will be less than 10 per cent, but in some instances losses could exceed 25 per cent.

Nitrogen and Vegetative Growth.—There is no question that a severe nitrogen deficiency reduces total tree growth and drastically reduces yield. However, effects of a slight to moderate deficiency are not so obvious. Smith (1969*a*) showed that, under conditions where 3 pounds of nitrogen per tree annually was judged to be an adequate commercial rate for grapefruit in Florida, the most obvious effect of lesser amounts was the lack of adequate foliage resulting from early abscission of mature leaves. Most of the leaf abscission occurred during and immediately following each period of new growth. Leaf and shoot production and ultimate tree size were essentially the same at nitrogen rates from 1 to 4 pounds per tree annually. Spring growth was intense at all nitrogen levels and most of the time the trees on low nitrogen were only slightly lighter green than those on high nitrogen.

Nitrogen and Root Growth.—Little evidence is available on root growth in the field as related to nitrogen fertilization. Ford, Reuther, and Smith (1957) observed, in two long-term fertilizer experiments in Florida, that high rates of nitrogen application reduced the concentration of feeder roots in the soil. In one experiment, the high-nitrogen plots had 37 per cent less feeder roots than the low-nitrogen plots to a depth of 5 feet. In the other, high-nitrogen plots had 38 per cent less feeder roots in the depth zones from 5 to 35 inches than did low-nitrogen plots. The deleterious effects of high nitrogen rates were probably caused by the resulting increase in soil acidity, which mobilized toxic amounts of residual copper (Smith, 1966; Spencer, 1963; Stewart *et al.*, 1961). In a grapefruit fertilizer experiment in Florida, Smith and Reuther (1955) and Smith and Rasmussen (1961*b*) found no significant effeet of rate or form of nitrogen fertilization on concentration of feeder roots in the soil where excessive amounts of copper had not been used and where soil acidity was controlled.

In central Florida, in contrast to broadcast applications of ammonium nitrate, anhydrous ammonia injections in the tree middles resulted in markedly more roots at the 12- to 42-inch depth under the area injected and less roots in the unfertilized area in the tree rows (Smith, 1965). Although there were two different nitrogen sources, the author was of the opinion that fertilizer distribution pattern and not nitrogen source was the factor influencing root distribution. In this same study, sodium nitrate as a nitrogen source resulted in sodium toxicity and a marked reduction in the concentration of roots in the soil.

In California, Cahoon *et al.* (1959), in a long-term experiment, found that forms of nitrogen influenced the concentration of Washington navel orange feeder roots to a depth of 3 feet. The highest concentration of roots was associated with urea, the lowest concentration with manure, and the effects of no fertilizer, calcium nitrate, ammonium nitrate, and sodium nitrate were intermediate. It is not clear from the data what mechanisms caused these effects on root density.

Phosphorus

Phosphorus considerations for tree crops differ widely from those of shallow-rooted annuals. Favorable responses from phosphorus applications to annual crops are widely observed, while such responses by tree crops are relatively rare; it is not uncommon, for example, to observe a phosphorus response by a cover crop in an orchard with no apparent responses by the tree crop. Lilleland, Brown, and Conrad (1942) found that, on one California soil, eighteen different annual crops failed to make satisfactory growth unless phosphorus was added; nevertheless, established fruit trees failed to show a favorable response to phosphorus additions. To satisfy the needs of an annual crop, a small mass of soil, which is explored by the roots, must supply relatively large quantities of phosphorus to the plant over a short period of time when the plant is making its most rapid growth. The roots of a tree crop explore a relatively large mass of soil and absorb phosphorus to some degree throughout the year. A tree also has greater storage capacity and accumulates some reserves to supplement its needs during the spring period of rapid metabolic activity and growth. Chapman (1934) concluded that "citrus trees may be able to secure ample phosphate from less available forms and lower total supplies than certain annual crops." Thus, the use of an annual plant for an

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indicator crop for phosphorus needs of a citrus tree is not a sound approach to the problem.

Only a small amount of phosphorus is removed from the orchard in the crop. Fruit removal from a California Washington navel orchard in a period of twenty-eight years accounted for only 2 per cent of the total phosphorus in the 0- to 36-inch layer of soil in the irrigated middles (Pratt *et al.*, 1956). A 500-box-per-acre (45,000 pounds per acre) Valencia crop in Florida removed only 10 pounds of phosphorus (Reitz, 1961), which is about the middle of the range of removal reported by Smith and Reuther (1953) where, under a variety of fertilizer practices, a range of 0.36 to 0.53 pounds of phosphorus per 2,000 pounds of fruit was reported to represent crop removal.

Generally, the phosphorus from applied materials does not move readily into lower soil depths. Bryan (1933) pointed out that the total, available, and water-soluble phosphorus in Florida soils increased with orchard age, apparently due to accumulation from long-continued application of phosphorus in fertilizers. By pot tests, this accumulated phosphorus was shown to be available to citrus. Over a four-year period, high phosphorus fertilization in a nineteen-year-old Valencia orange orchard situated on a hammock phase of Lakeland fine sand in Florida, increased the total phosphorus in the first foot of soil by 577 pounds per acre but did not increase yield (Reuther *et al.*, 1949). Wander (1950) showed that large quantities of phosphorus accumulated in citrus soils in central Florida under the common system of management. In a Lakeland fine sand in Florida, over an eleven-year period, essentially all the applied phosphorus was shown to be retained in the 7-foot citrus-root feeding zone (Spencer, 1957). In unlimed plots, where soil pH had dropped to approximately 4.0, the total phosphorus concentration was low in the surface 6 inches with a large accumulation in the 12- to 36-inch depth zone. In plots limed to pH 5.5 to 6.0 the concentration was highest in the surface 6 inches, and it decreased rapidly with depth. By both pot tests and use of phosphorus radioisotopes, this accumulated phosphorus was proven to be available to citrus plants. Smith (1956), working in a Pineapple orange experiment on an acid sand in Florida, found that after thirteen years of phosphorus fertilization, most of the added phosphorus was in the top foot of soil, but there was gradual accumulation throughout the top 5 feet. Phosphorus was not reported to be present in subsurface drainage water taken from the foot of a hillside orchard (Wander, 1951).

Studies in a long-term fertilizer experiment in California, on a Ramona sandy loam with a surface soil pH of 7.6, showed that over a twenty-eight-year period the phosphorus from applied phosphorus and manure could be accounted for in the 0- to 36-inch depth, with 60 per cent in the 0- to 6-inch depth and 80 per cent in the 0- to 12-inch depth (Pratt *et al.*, 1956). This same study showed that in plots receiving no phosphorus there was loss of 408 pounds of phosphorus per acre from the irrigated row middles. About 7 per cent of the phosphorus from the row middles had undergone absorption and redistribution by the trees. Chapman (1934) in a survey in California showed substantial gains in phosphorus in citrus soils as a result of past fertilizer practices.

Generally, the soluble forms of phosphorus are preferred for fertilizer use. In the acid mineral soils of Florida, Wander (1954*b*) found that sweet orange seedlings in 10-inch pots did not respond as well to colloidal or rock phosphate that was worked into the top 3 inches of soil at rates up to 9 tons of material per acre, as they did to the soluble monocalcium phosphate. However, on a Davie mucky fine sand, an organic soil with a pH of from 4.8 to 5.5, rock phosphates were satisfactory over a nine-year period at a total phosphorus rate three times as high as the superphosphate rate (Young and Forsee, 1949). Finely ground rock phosphate and soft rock phosphate were not effective on young nonbearing trees on a calcareous flatwoods soil in Florida, but both were effective on an acid flatwoods soil (Anderson and Calvert, 1967).

In a pot test with acid soil in Australia, a greater growth response of orange seedlings was obtained from 37 per cent rock phosphate and granulated superphosphate than from superphosphate used at an equivalent rate (Bouma, 1960).

Average analysis of a number of inorganic phosphorus fertilizer materials is shown in table 5–1 (see p. 128).

Some of the organic materials supply moderate amounts of phosphorus. Pratt *et al.* (1956) showed that, over a twenty-eight-year period, appreciable quantities of phosphorus had accumulated in surface soil from applications of manure (steer, feedlot) and cottonseed meal, while no significant accumulation resulted from applications of alfalfa hay, bean straw, and cereal

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straw. Observations indicate that animal manures are an efficient source of phosphorus for citrus trees. Castor pomace and processed sewage sludge appear also to have value as phosphorus source materials (Young and Forsee, 1949; Spencer, 1963).

The amounts of phosphorus in organic materials varies among different sources and between different lots of the same material. Average phosphorus analyses of a number of organic materials are shown in table 5–3 (see p.136). Phosphorus fertilizers from western sources in the United States contain appreciable quantities of zinc (Bingham, 1959).

The effects of phosphorus on root growth are discussed later in the section on crop yields (p. 158).

Potassium

Potassium deficiency of citrus sufficiently severe to bring on leaf symptoms is not commonly observed under orchard conditions, but has been reported in Australia (Arnot, 1946), California (Embleton, Jones, and Page, 1964, 1966), and Florida (Koo and Spencer, 1959; Smith and Rasmussen, 1961*c*).

A temporary stress for potassium, induced as the "on crop" approaches maturity, appears to be associated with Murcott tangor collapse in Florida (Stewart *et al.*, 1968.)

The potassium ion is readily bound on the exchange complex of the soil, and thus accumulates in surface soils. Pratt *et al.* (1959) found that after twenty-eight years in an irrigated soil in California, exchangeable plus soluble potassium in the soil in row middles did not decrease where no potassium was added. The potassium release from nonexchangeable forms completely replenished or balanced that removed in the fruit or accumulated as a result of leaf fall. Most of the potassium added in fertilizer salts or manure over the twenty-eight-year period remained in the top 2 feet of soil.

In sandy soils, such as those of central Florida where the cation-exchange capacity is very low, the amount of potassium held by the exchange complex is low and readily replaced by other cations (Peech, 1939; Spencer, 1954). This does not necessarily imply loss due to leaching. In a central Florida experiment on deep sand (Koo, 1962), differential potassium application was discontinued after fifteen years. Most of the extractable potassium was lost from the surface 6 inches of soil in the four succeeding years. However, total loss of extractable potassium from the 0- to 120-inch profile (40 to 212 pounds per acre) was very nearly accounted for by fruit removal (45 to 203 pounds per acre). The ranges in loss and removal were related to the previous potassium-fertilizer rates.

It is commonly observed that concentrations of potassium are higher and those of calcium lower in leaves from trees growing on the acid sandy soils of central Florida than in leaves from Texas, Arizona, California, or the Indian River area of Florida, where the whole soil profile or subsoil is higher in calcium. On central Florida soils, very high levels of leaf potassium can result from potassium fertilization. Where high-calcium soil exists in the profile, heavy potassium fertilization results in substantially lower leaf levels of potassium than on acid sandy soils (Reitz and Long, 1952; Reuther, Smith, and Specht, 1949). From this, one could deduce that the soil pH and calcium content directly control the maximum obtainable potassium level in leaves. However, pot-culture studies (Martin, Ervin, and Shepherd, 1961; Martin and Page, 1962, 1965; Smith, 1964) show that the explanation is not this simple and needs further study.

Regardless of the explanation, high-potassium leaf values found in central Florida have not been observed from trees growing in high-calcium soils, even with high rates of potassium fertilization. For this reason, one-fourth more potassium is recommended for calcareous or marl soils in Florida than for acid soils (Reitz *et al.*, 1972).

In California, the time for soil applications of potassium to become effective varies from almost immediate (Embleton *et al.*, 1966) to practically no response many years after massive applications (Chapman, 1964). This variation appears to be associated with the rate at which the potassium moves into the root zone. Factors affecting movement into the root zone are the soil's cation-exchange capacity and potassium-fixation capacity. Salinity and the magnesium concentration in the exchange complex may limit the response (Embleton, Jones, and Page, 1967; Page *et al.*, 1969).

Evidence is available suggesting that soil potassium may become excessively high. Under some conditions, a growth reduction of young citrus trees in the greenhouse occurred with exchangeable-potassium levels in the soil as low as 10 per cent of the exchange complex. Soil type and rootstocks influenced the degree of growth

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reduction. Greater reductions in growth occurred in soils with the higher cation-exchange capacities (Jones, Martin, and Bitters, 1957; Martin, Bitters, and Ervin, 1959). Where animal manure was used to supply 3 pounds of nitrogen per tree annually over a twenty-eight-year period, the potassium saturation of the exchange complex in the surface 6 inches of soil approached 20 per cent, while natively the soil potassium saturation was about 4 per cent. This occurred where about 650 pounds of potassium per acre were applied annually for the last fifteen years involved. Where manures plus mineral salts of potassium were applied, potassium saturation values of about 25 per cent were found in the surface 6 inches of soil (Pratt *et al.*, 1959). This suggests that continuous use of large quantities of animal manure or mineral potassium salts or both may result in soil conditions unfavorable for the growth of citrus trees.

Ample evidence is available showing that soil applications of materials containing potassium may induce or accentuate magnesium deficiency (McColloch, Bingham, and Aldrich, 1957; Reitz and Koo, 1960; Reuther and Smith, 1952*b*). Because of these possible secondary effects, and other effects (see chap. 6), one should not use potassium fertilizer indiscriminately. The average composition of the common potassium mineral fertilizers appears in table 5–1 (see p. 128). The average amount of potassium in a number of organic materials appears in table 5–3 (see p. 136).

Sprays of potassium nitrate were effective in increasing potassium concentrations in orange and lemon leaves (Calvert, 1969; Cutuli, 1968; Embleton *et al.*, 1964, 1966; Page, Martin, and Ganje, 1963). Experimental sprays up to 40 pounds of potassium nitrate per 100 gallons of water at the rate of about 700 gallons per acre have been used successfully in the field in California; in Florida, slight leaf burn was observed at this rate (Calvert, 1969). A rate of 30 pounds per 100 gallons is being used commercially in California.

Calcium

There is only one documented occurrence of calcium deficiency in citrus in the field. This deficiency occurred in Florida where no lime or other calcium-bearing material had been applied (Spencer and Koo, 1962).

In citrus production, the factors of primary concern are those associated with the indirect effects of calcium and not its direct effects as a nutrient. These indirect effects will be discussed later in the section on soil amendments (see p. 149).

Magnesium

Citrus magnesium deficiency has been reported from many of the world's citrus-growing areas (Embleton and Jones, 1959*a*). Probably the most widespread magnesium deficiency of citrus once occurred in Florida. Long before magnesium deficiency per se was recognized, magnesium was being applied to citrus as an impurity in fertilizers and soil amendments (Camp, 1947). The introduction of new, purer chemical materials and gradual elimination of the magnesium-bearing materials brought on a general state of deficiency in the twenties and thirties which severely limited citrus production in Florida. Undoubtedly, heavy potassium fertilization aggravated magnesium deficiency. The widespread addition of magnesium in the fertilizer program in Florida developed in the mid-thirties.

In California, it has been shown that magnesium in the soil increases with depth (Pratt *et al.*, 1959). Over a twenty-eight year period in a long-term fertilizer experiment there was a substantial reduction in the amount of exchangeable magnesium in the soil, and the reduction was highly correlated with the amounts of salts added as fertilizers or soil amendments (Pratt and Harding, 1957*a*, 1957*b*). It was theorized that, with soils of low cation-exchange capacity, the use of high-calcium, low-magnesium irrigation waters would be most likely to produce magnesium deficiencies (Pratt and Harding, 1957*a*). Thus, one of the impacts of intensive irrigation agriculture on soils is the downward movement of magnesium in the profile. This may explain why mild magnesium-deficiency symptoms have been rather common in California in recent years. The addition of chemical fertilizers or manures to many crops increased the magnesium losses from the soil (Jacob, 1958). Jacoby (1961) concluded that a high exchangeable calcium-magnesium ratio in the soil impaired magnesium uptake by citrus trees in Israel. Hence, magnesium deficiency is likely to be more of a problem in the future where corrective measures are not employed.

Soil application of magnesium materials have been effective in Florida. The present recommended program for acid sandy soils (Reitz *et al.*, 1972) is to apply magnesium sulfate or oxide in the fertilizer. Dolomite used to control pH be-

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tween 5.5 and 6.5 provides supplementary amounts. If calcium limestone is used to control soil pH, greater amounts of magnesium must be applied in the fertilizer. Recommendations also call for higher rates to be applied to calcareous soils since soil applications are less effective under alkaline calcareous soil conditions. One report has shown that, over a sixteen-year period, high rates of magnesium sulfate applied to mature Marsh grapefruit trees growing on a Parkwood loamy fine (calcareous) sand in Florida's Indian River area were only partially effective (Calvert and Reitz, 1966).

Early experiments in Florida gave variable results from use of water-insoluble materials, but recent experiments showed that magnesium oxide soil applications were effective on Leon fine sand in the Indian River area and Lakeland fine sand in central Florida. Soil pH in the experimental areas ranged from 5.1 to 7.4. Leaf uptake of magnesium was detected nine months after application of either oxide or sulfate, but only after 24 months following application of carbonate (Koo, 1972; Koo and Calvert, 1966). Dolomite can probably maintain adequate magnesium supplies to groves under Florida conditions (Anderson, 1971). In an experiment with Temple oranges at the University of Florida Indian River Field Laboratory, where the pH in the top 12 inches of soil ranged from 5.4 to 6.5, both magnesium sulfate and dolomite soil applications were effective in increasing the already adequate levels of leaf magnesium (Calvert, 1970).

On a sandy, acid soil in California, massive applications of dolomite did not significantly influence magnesium concentration in the leaves over a three-year period (Embleton, Jones, and Kirkpatrick, 1956), but, on these same soils, 50 pounds of Epsom salts per tree resulted in substantial increases in magnesium concentration in the leaves from 12 to 18 months after application, and applications were effective for at least seven years (Embleton and Jones, 1959*a*). In this same orchard, 1.3 pounds of magnesium per tree, as magnesium oxide, applied to the soil annually for five years, was about as effective as one annual spray of magnesium nitrate; however 5 pounds of magnesium, as magnesium oxide, applied to the soil annually was considerably more effective (table 5–4). Yields were not different in this experiment.

McColloch *et al.* (1957) also observed an increase in leaf magnesium from soil applications of Epsom salts to orange trees growing in a sandy (probably acid) soil in California. However, they observed that on a clay soil (high-cation-exchange capacity) a total of 195 pounds of Epsom salts per tree applied from 1948 to 1954 did not result in an adequate increase in leaf magnesium concentration. In other experiments in California, soil applications of magnesium sulfate on sandy loam soils were ineffective (Jones, Embleton and Opitz, 1971) or gave only temporary benefit (Haas, 1948). In Israel, soil applications of magnesium chloride and magnesium sulfate were not effective in correcting magnesium deficiency (Heymann-Herschberg, 1951). In South Africa, soil applications of magnesium sulfate and dolomite were slow in giving a response (DeVilliers, 1942; Oberholzer, 1947), and several years longer were required for magnesium to reach the leaves when applied to the soil as magnesium carbonate than when applied as magnesium sulfate (Bester, 1969; De Villiers, 1969).

Table 5–4

EFFECT OF SPRAYS OF MAGNESIUM NITRATE AND SOIL APPLICATIONS OF MAGNESIUM OXIDE ON MAGNESIUM CONCENTRATION IN LEAVES OF MATURE VALENCIA ORANGE TREES*

	Per Cent Magnesium in Dry Leaves†					
Treatments	1958	1960	1961	1962	1963	1964
Check	0.28_y	0.30_z	0.23_z	0.28_z	0.28_z	0.32_z
Spray	0.32_z	0.34_{zy}	0.31_{yz}	0.35_y	0.36_y	0.39_y
Soil rate 1	0.29_y	0.36_y	0.26_{zy}	0.37_y	0.36_y	0.38_y
Soil rate 2	0.31_{yz}	0.42_z	0.34_z	0.48_z	0.50_z	0.54_z

* Trees were growing on a well-drained, acid Ramona stony sandy loam. Near Pala, California, there were nine replications of single-tree plots. Treatments were a check, sprays of 10 pounds of magnesium nitrate per 100 gallons of water applied each year when the spring growth was about three-fourths expanded, magnesium oxide broadcast around the dripline of the trees in November, 1957 and in the spring of 1958, 1959, 1960, and 1961, in an amount to supply for each application 1.3 pounds of magnesium per tree for rate 1 and 5 pounds of magnesium for rate 2.

† Spring-cycle leaves from nonfruiting terminals were sampled in the mid-August to mid-October period. Means were ranked by Duncan's (1955) multiple range test as modified by Harter (1960). Means are significantly different at the 0.01 level if they do not have a subscript letter in common.

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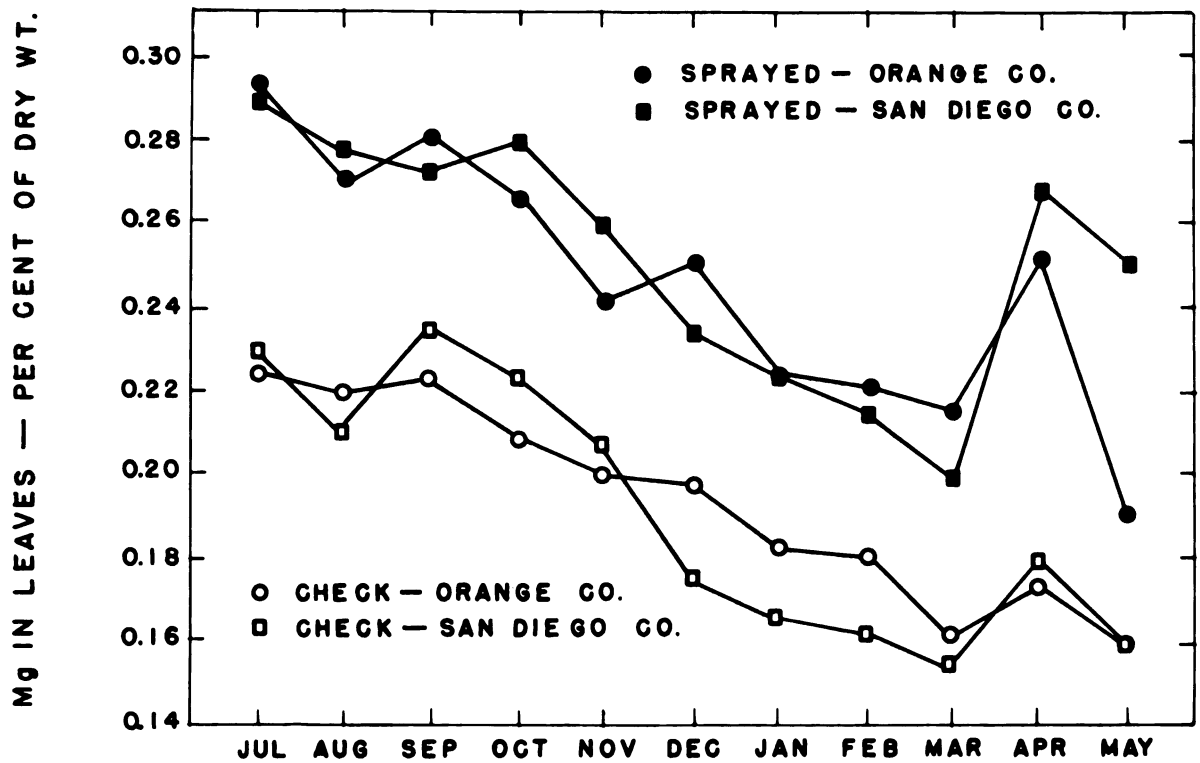

Fig. 5–5. Comparison of concentrations of magnesium in spring-cycle, nonchlorotic leaves from check trees and trees sprayed with 10 pounds of magnesium nitrate per 100 gallons of water. In the Orange County experiment, each point on graph is the mean from 24 trees. In the San Diego County experiment, each point is the mean from five trees.

It appears that soil applications of magnesium are most effective on acid sandy soils such as those in central Florida, and possibly Japan (Koto, Takeshita, and Nakajima, 1963). Soil applications have not been successful or were very slowly effective under alkaline, fine-textured soil conditions.

Magnesium sulfate foliage sprays to citrus have been unsuccessful, or resulted in only partial corrections of magnesium deficiency symptoms in leaves (Haas, 1948; Heymann-Herschberg, 1951; Tait, 1936).

Sprays of magnesium nitrate were effective in preventing the occurrence of magnesium deficiency symptoms in California (Embleton and Jones, 1959*a;* Jones, et al., 1971) and markedly reduced the symptoms on grapefruit and oranges in Florida (Calvert and Reitz, 1966), and gave complete correction of magnesium-deficiency symptoms on marcotted Persian limes in southern Florida (Koo and Young, 1969). Best results from such sprays were achieved from applications when the spring flush of growth was from two-thirds to three-fourths expanded. The data in figure 5–5 show that one spray of magnesium nitrate increased the magnesium concentration in young leaves, and that sprayed leaves remained higher in magnesium concentration until time to spray again the following year. In the two experiments from which data in figure 5–5 were obtained, magnesium deficiency symptoms on unsprayed leaves appeared in increased numbers after September. Increase in symptoms coincided with magnesium concentration in nonchlorotic leaves dropping below 0.20 per cent. Leaves with magnesium deficiency patterns normally contain less than 0.07 per cent of magnesium. A mild deficiency (0.16 to 0.20 per cent magnesium in five- to seven-month-old nonchlorotic bloom-cycle leaves from nonfruiting terminals) can be corrected by one magnesium nitrate spray a year. A moderate deficiency (0.12 to 0.16 per cent of magnesium) can be corrected by two sprays about one month apart. A severe deficiency (less than 0.12 per cent of magnesium) may require three sprays about a month apart for correction. Unfortunately, very little magnesium from foliage sprays is translocated from old foliage to young foliage (Jones

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Table 5–5
SUMMARY OF INCREASES IN MAGNESIUM CONCENTRATIONS IN NONCHLOROTIC ORANGE LEAVES, FROM VARIOUS CALIFORNIA LOCATIONS, THAT RESULTED FROM MAGNESIUM NITRATE FOLIAGE SPRAYS APPLIED WHEN SPRING-FLUSH LEAVES WERE ABOUT TWO-THIRDS EXPANDED

Variety	County	Date Leaves Sampled	Pounds Magnesium Nitrate Per 100 Gallons of Spray	
			0	10
			Per Cent Magnesium in Leaves	
Valencia	San Diego	Aug. 25, 1959	0.235	0.265
Valencia	Orange	May 2, 1959	0.161	0.193
Valencia	Ventura	May 27, 1959	0.152	0.198
Navel	Tulare	May 11, 1959	0.159	0.205
Navel	Tulare	May 12, 1959	0.187	0.219

Source: Embleton and Jones (1959*b*).

et al., 1971). Therefore, annual sprays probably will be required to keep the deficiency under control. Some typical results of single magnesium nitrate sprays are shown in table 5–5. One spray of 10 pounds of magnesium nitrate per 100 gallons of water applied in late April or early May generally increased the percentage of magnesium in leaves by 0.03 to 0.04.

Magnesium nitrate salt is expensive and hygroscopic. Epsom salts (magnesium sulfate) and calcium nitrate can be mixed in the spray tank to form magnesium nitrate, giving a spray material that is equal in effectiveness to the more expensive magnesium nitrate salt (Calvert and Reitz, 1966; Platt, 1968). A successful preparation method has been to use 10 pounds of Epsom salts and 10 pounds of calcium nitrate per 100 gallons of water.

In Israel, Bar-Akiva, Tal, and Hirsh (1969) reported that as a foliar spray, magnesium nitrate was more effective than magnesium sulfate. They further reported that magnesium nitrate can be applied either by high- or low-volume types of sprayers. In addition, they showed that two airplane applications (autumn and spring) of 5 gallons of Magniosan (a preparation containing 55 per cent magnesium nitrate) in 20 gallons of water per acre increased the magnesium content in Valencia orange leaves from 0.095 to 0.190 per cent. They also applied, by airplane, 5 gallons of Magniosan per acre without dilution, and observed no toxic effects.

Sulfur

Although sulfur deficiency of citrus has been demonstrated in soil cultures (Chapman and Brown, 1941), a deficiency has not been reported under field conditions. Some California and Texas irrigation waters contain large sulfate quantities, and excess symptoms have developed from their use. Under some conditions sulfur excess symptoms and the resultant adverse effect on yields can be reduced by an increase in nitrogen in the tree (Chapman and Liebig, 1940; Foote and McElhiney, 1937; Haas and Thomas, 1928; Jones *et al.*, 1963). Sulfur effects are largely indirect and will be covered later in this chapter (see p. 149).

Boron

Boron deficiency of citrus in the field has been reported from Japan (Satō *et al.*, 1962), South Africa (Morris, 1938), California (Opitz and Platt, 1967), and Florida (Smith and Reuther, 1949; Smith, 1954). Even in South Africa and Florida the deficiency is seldom observed, probably because boron has been applied as an impurity in fertilizers and soil amendments (Smith and Reuther, 1954). Where the deficiency does occur, sprays of 1 pound of borax (11 per cent of B, 36 per cent of B_2O_3) or boron soil applications (calculated as B_2O_3) equivalent to $\frac{1}{100}$ of the annual nitrogen rate are recommended (Reitz *et al.*, 1972). The range between boron deficiency and excess is small, so recommended application rates should be followed closely.

Excesses of boron are of far greater commercial concern than deficiencies. In California and Texas, irrigation waters high in boron are frequently encountered with the resultant toxic effects on trees. Where excess boron is in the irrigation water, toxic effects can be reduced by irrigating in such a manner that the boron concentration in the soil solution is maintained at or near the concentration of boron in the irrigation water. As the boron concentration in the soil solution increases, toxic effects on the trees increase.

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Where nitrogen is not already high in the tree, toxic effects of boron can be reduced by increasing the nitrogen fertilization rate (Chapman and Liebig, 1940; Eaton, 1935; Haas and Thomas, 1928; Foote and McElhiney, 1937; Jones *et al.*, 1963).

Occasionally, manures are encountered that contain boron in amounts high enough to produce some toxic symptoms on trees. When sprinkler-applied irrigation water wetted the foliage, boron toxicity (leaf burn) developed if the concentration of boron in the irrigation water approached 0.5 ppm in the summer (Stolzy, Harding, and Branson, 1966).

Iron

Iron deficiency of citrus can be caused by many factors. Although there can be an iron deficiency in the soil, this is not common. Iron is more abundant in the earth's crust than most of the other essential mineral elements (Hodgson, Leach, and Allaway, 1962), and yet iron deficiency is, in general, the most difficult citrus nutrient deficiency to correct. It is commonly associated with an accumulation of lime in the soil, and is then referred to as "lime-induced chlorosis." Iron is present in soil, but in a form that is unavailable to the tree. The iron concentration in leaves is reduced by wet soil or excessive water, low oxygen concentration in the root zone, cool soil temperature, or combinations of these (Burgess and Pohlman, 1928; Labanauskas, Jones, and Embleton, 1962; Jones *et al.*, 1961; Naudé, 1958; Stolzy *et al.*, 1963; Wallihan *et al.*, 1961; Wallihan and Garber, 1968). In Florida, iron deficiency is associated with accumulations of copper in the soil (Reuther and Smith, 1952*a*, 1953; Smith and Specht, 1952).

Successful correction of the deficiency has been achieved on sandy, acid soils in Florida by application of iron chelates (Ford, 1953; Leonard and Stewart, 1952; Stewart and Leonard, 1952*a*, 1952*b*), and by liming to inactivate excessive amounts of copper (Reuther and Smith, 1952*a*, 1953; Stewart and Leonard, 1957). There is some evidence that correction of copper toxicity with iron chelates may be associated with the chelate molecule and not with iron *per se* (DeKock, 1956; DeKock and Mitchell, 1957).

On calcareous soils, control of the deficiency is very difficult. In general, results from use of iron chelates have been only partially successful (Armstrong and Furr, 1956; Cooper and Peynado, 1954, 1959; Demetriades, Gavalas, and Papadopoulos, 1964; Hilgeman, 1957; Kuykendall, Hilgeman, and Van Horn, 1957; Stewart and Leonard, 1957; Wallihan and Embleton, 1961; Wallihan, Embleton, and Sharpless, 1969; Wallihan *et al.*, 1954).

Zinc

Like many of the essential elements, zinc may exist in the soil in forms unavailable to trees. Zinc deficiency was a major limiting factor in citrus production in California and other parts of the world until it was identified in the 1930's.

Early experiments in Florida and California showed that soil applications of zinc sulfate gave inconsistent results. Comparable applications of zinc sulfate produced various responses, from no effect, or partial or complete recovery, to injury or even death of trees (Camp, 1934; Johnston, 1933; Parker, 1934).

Later experiments in Florida indicated that soil applications of zinc sulfate to acid soils can be successfully used if applied at 5 pounds or more per tree in combination with an equal amount of calcium chloride in bands or small piles of the materials under the trees. Zinc chelate (EDTA) was effective if applied to the soil with sodium carbonate in small piles or narrow bands under the tree. The sodium carbonate raised the pH of the soil under the pile to 10.0 or higher, stabilizing the zinc chelate (Leonard, Stewart, and Edwards, 1958; Stewart and Leonard, 1963).

In an experiment with oranges on acid sands in Florida, zinc sulfate was broadcast at rates supplying from 25 to 150 pounds of zinc per acre and plowed into the soil. This resulted in substantial increases of zinc concentration in leaves, and the single applications were effective for at least twelve years (Smith, 1967*b*). Differential applications of liming materials reduced the effectiveness of soil-applied zinc, but absorption was still adequate at pH values above 7 (Smith and Rasmussen, 1959).

In a twenty-year phosphorus fertilizer experiment established on virgin acid sand in Florida, soil applications of zinc were reported to be entirely satisfactory. Zinc was included in the fertilizer for an eleven-year period at the rate of 7 pounds of zinc per acre annually. The orange trees were five years old when zinc was first applied (Smith, Scudder, and Hrnciar, 1963).

The effectiveness of soil applications of zinc to a virgin Lakeland fine sand in Florida was again demonstrated with nucellar Valencia orange trees on rough lemon rootstock. One or two pounds of zinc per two-year-old tree were applied

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as zinc sulfate, zinc oxide, or zinc sulfide. Materials were broadcast on the surface of the soil around each tree, applied in a narrow band on the surface around each tree, or applied in a narrow trench around each tree. Five years after treatment both zinc sulfate and zinc oxide were effective in increasing the zinc concentration in leaves when banded or surface broadcast. Zinc sulfide was not as effective as the other materials, nor was subsoil banding as effective as the other methods (Smith, 1967*b*).

Experiments in California on soils above pH 7 showed that soil applications of zinc chelates were generally unsuccessful. Soil applications of zinc sulfate up to 10 pounds per tree were effective in some orchards but not in others. On alkaline sandy soils in the Coachella Valley, soil applications of up to 10 pounds of a mixture of equal parts of zinc sulfate and calcium chloride, in piles or banded at the dripline, were very effective in increasing zinc concentration in leaves, but such applications resulted in various degrees of injury and, therefore, were not recommended. When soil applications were effective, zinc concentrations in leaves were significantly higher for two or more years (Embleton, Wallihan *et al.*, 1964).

On Valencia oranges, in an inland area in Ventura County, California, the prevention of mild zinc deficiency symptoms on the spring-cycle foliage by zinc sprays did not increase yields, even though the zinc concentration in young spring-cycle leaves, one year after application of zinc sprays, was increased from about 13 to 19 ppm (Labanauskas, Jones, and Embleton, 1963). Similar results were observed on Valencia oranges in San Bernardino County, California (Labanauskas and Puffer, 1964). However, in a coastal lemon experiment in California, with a soil pH of about 7.3, where there were no visible symptoms of zinc deficiency on treated or control trees, soil applications of zinc sulfate increased both the zinc concentration in leaves and fruit yields. This indicates that yield of lemons is affected at a level of zinc in the leaves higher than that associated with the expression of visual symptoms of zinc deficiency on leaves. One zinc spray in the spring, to lemons that bloom and set fruit more or less throughout the year, was not effective (Embleton, Wallihan, and Goodall, 1965).

Zinc applied to either acid or alkaline soils is usually adsorbed or precipitated in the surface and does not move readily into the root zone. Therefore, applying zinc materials in a number of holes or piles, or in a narrow band at the dripline of the tree, has been more successful than broadcast applications.

Generally, on oranges and grapefruit the deficiency can be corrected by spray applications of a number of zinc materials. Common sprays are 3 pounds of zinc sulfate (36 per cent zinc) plus 1½ pounds of hydrated lime or soda ash, or 1 pound of zinc sulfate without a precipitating agent, or 2 to 3 pounds of zinc oxide per 100 gallons of water (Labanauskas, Jones, and Embleton, 1969; Platt, 1968). On occasion, poor results have been obtained by applying a zinc spray before the spring cycle of growth appeared. Such a spray corrected the deficiency symptoms on sprayed leaves, but the growth that came out after spraying had zinc deficiency symptoms. Sprays have been more successful when applied shortly after a major growth cycle expanded. With oranges and grapefruit in California, one spray in the spring has usually been adequate for maintenance purposes; however, in desert areas, two annual zinc sprays, when the spring-growth cycle and the fall-growth cycle are expanded, may be necessary to control visible deficiency symptoms (Labanauskas, unpublished).

Zinc is not readily translocated from old to new leaves. Studies using radioactive zinc showed that zinc may be absorbed through both the upper and lower surfaces of leaves, as well as through the bark on twigs. Movement of zinc in the plant was always from basal toward distal portions. Movement out of an individual leaf into other surrounding leaves was not observed. Zinc applied to the bark of twigs moved outward into most of the leaves on the twig. Little absorption of zinc by leaves occurred in the dormant season, but absorption took place readily into new leaves in the postbloom period (Stewart, Leonard, and Edwards, 1955). Studies by Wallihan and Heymann-Herschberg (1956) with radioactive zinc confirm uniform absorption of zinc by upper and lower surfaces of citrus leaves. They also showed that young leaves absorb zinc more readily than older ones.

The effectiveness of a spray is determined by the concentration of zinc ions in the spray solution. The concentration of zinc ions in solution is determined by the kind and amount of zinc material used, other materials used with zinc, and water quality. Low residue sprays of 1 pound of zinc sulfate (36 per cent zinc) per 100 gallons of water are being used commercially with success (Labanauskas, 1969; Labanausakas *et al.*, 1969).

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Manganese

Symptoms of manganese deficiency on young leaves are common in many citrus districts of the world. As leaves age, symptoms usually disappear, so if symptoms persist on older leaves, corrective measures should be considered.

Manganese may exist in soil in an unavailable form or there may be an actual manganese deficiency. In alkaline soils in arid regions, manganese is usually present in an unavailable form.

Manganese excess in citrus has been reported in Australia (Bowman, 1956), South Africa (Van der Merwe and Anderssen, 1937), and Japan (Yuda, 1970). Large amounts of manganese have accumulated in the top foot of the acid, sandy soils of Florida, where it has been applied continuously over a period of years in the fertilizer program (Reuther and Smith, 1952*a*; Wander, 1954*a*). Present recommendations in Florida are to apply manganese only where manganese deficiency symptoms persist (Reitz *et al.*, 1972).

Both spray and soil applications of manganese are effective on trees growing in acid sands of Florida, but the material is commonly applied to the soil (Leonard, 1969). Manganese soil applications were effective on acid soils in Japan (Koto *et al.*, 1963). In regions where soils are alkaline or calcareous, manganese is generally applied as a spray. Common sprays are 3 pounds of manganese sulfate and 1½ pounds of hydrated lime or soda ash per 100 gallons of water or 1 pound of manganese sulfate (28 per cent manganese) per 100 gallons without a precipitating agent (Labanauskas *et al.*, 1969; Platt, 1968). Stewart and Leonard (1963) showed that, on calcareous soils, applications of a mixture of manganese sulfate and calcium chloride in piles or in a band around trees were effective in increasing leaf manganese concentration. There has been some difficulty in correcting manganese deficiency symptoms in desert regions. As with zinc, this difficulty has been associated with very little translocation of manganese from old to new leaves. Labanauskas (1962) showed that the deficiency in California desert areas can be corrected with two sprays a year, one in April and one in November, while Hilgeman and Sharples (1968) showed that the deficiency in Arizona's desert can also be corrected with two sprays a year, one in winter and another in spring.

Like zinc, the effectiveness of a manganese spray is dependent upon the concentration of manganese ions in the spray solution. The concentration of ions in solution is determined by the kind and amount of manganese material used, other materials used with manganese, and water quality (Labanauskas, 1962; Labanauskas *et al.*, 1969).

Copper

Copper deficiency has been reported from many citrus-growing areas of the world. Probably the most widespread deficiency once occurred on acid, sandy soils in Florida. The trouble was recognized as early as 1875, and successful treatments with copper sprays were reported several decades later (Floyd, 1914). The success of soil treatments with copper sulfate soon followed (Grossenbacher, 1916). After this, copper was generally applied in fertilizer and in pest-control spray. In some orchards, toxic amounts of copper accumulated in the surface soil, resulting in iron chlorosis, unthrifty and stubby fibrous roots in the topsoil, dieback, and unproductive trees (Ford, 1953; Reuther and Smith, 1952*a*, 1953; Reuther, Smith, and Scudder, 1953; Smith and Specht, 1952). Recommendations in Florida are to apply no copper in fertilizer to old groves unless copper deficiency symptoms occur, and to maintain soil pH between 6.5 and 7.0 if the soil contains 100 pounds or more of copper per acre (Reitz *et al.*, 1972).

Generally, the more clay in the soil, the greater the tolerable amount of copper (Reitz and Shimp, 1953). Also, copper toxicity is reduced with an increase in soil pH. Copper toxicity from soil copper has not been reported from areas with alkaline soils.

If it were not for use of copper in many pest-control programs, copper deficiency would probably be more widespread in areas where it is not used in the fertilizer program. In California, the deficiency is observed only occasionally and is readily corrected by copper sprays. A safe spray is 3 pounds of copper sulfate and 4½ pounds of hydrated lime per 100 gallons of water (Platt, 1968). Soil applications of copper are generally not suggested for alkaline soils, in which applied copper is adsorbed or precipitated in the surface soil. Even for acid soils in Florida, copper deficiency is more readily corrected by spray than by soil applications (Reitz *et al.*, 1972).

Damage to foliage and fruit can result from Bordeaux and other copper sprays (Klotz, Calavan, and DeWolfe, 1956; Platt, 1968). In California, injury may be more severe in some areas than others. In areas where injury does occur,

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more hydrated lime should be added to the Bordeaux mixture, and the addition of some hydrated lime to the one-package commercial formulations will give added safety. Copper sprays should be applied only if the need has been well established. Why copper sprays tend to injure citrus trees more frequently under California than Florida conditions has not been adequately explained.

Copper appears to be very mobile in the citrus tree (Smith and Reuther, 1954). Therefore, time of spraying to correct a copper deficiency is not critical.

Molybdenum

Molybdenum deficiency has been identified on many crops throughout the world, and is usually associated with acid soils. Symptoms of the deficiency in citrus were observed early in the century in Florida (Floyd, 1908), but not identified until about 1950 (Stewart and Leonard, 1951). It is recommended that the soil reaction be adjusted to pH 5.5 to 7.0 and maintained at this level, and that sprays of 1 ounce sodium molybdate per 100 gallons of water be applied if symptoms are mild and 2 ounces per 100 gallons if symptoms are severe. Preferably, sprays should be applied in spring or summer, since sprays applied in October or later usually will not cause regreening of the yellow spots. However, sprays applied shortly before the spring cycle of growth appears will prevent occurrence of the symptoms on that growth the following summer. Soil applications have not been effective in correcting the deficiency (Reitz *et al.*, 1972).

Chlorine

Although it has been demonstrated that chlorine is an essential element for growth of green plants, the essentiality to citrus *per se* has, as yet, not been demonstrated. However, excesses of chloride have been observed in citrus resulting from chloride in irrigation water that was applied to soil (Cooper, 1961; Holevas and Demetriades, 1963) or deposited on foliage by sprinklers (Harding, Miller, and Fireman, 1958; Smith, 1963). Again, proper irrigation procedures are of prime importance in combating chloride excesses. On occasion, burn from excess chloride has been observed where a chloride-containing fertilizer such as potassium chloride has been applied to citrus trees in large amounts to supply potassium.

Sodium

Sodium is an essential element for plant growth (Brownell, 1965; Brownell and Wood, 1957), but it is highly unlikely that it will ever be deficient under field conditions. Excessive sodium, however, is not uncommon in some irrigation waters, and use of such water results in excessive sodium accumulation in trees and deterioration of the structure of some soils. Harding, Miller *et al.* (1958) showed that excessive sodium accumulated in the leaves from sprinkler irrigation water striking them.

On a well-drained, acid soil in California, applications of 2 pounds of nitrogen per orange tree annually in the form of sodium nitrate had to be discontinued after five years because of leaf burn and defoliation. Applications of sodium carbonate to increase the soil pH to between 7.0 and 7.5 also resulted in leaf burn and defoliation. Three annual sprays of monosodium phosphate and disodium phosphate at concentrations of 1 pound of phosphorus per 100 gallons resulted in leaf burn and defoliation after three years. Water penetration was not, on the soil in question, a contributing factor to leaf burn and defoliation. Although total salts in irrigation water used in this orchard were low, sodium salts predominated, and this probably hastened the adverse effects from the above treatments. Leaf burn and defoliation occurred when the percentage of sodium in healthy, five- to seven-month-old, bloom-cycle leaves from nonfruiting terminals exceeded 0.20 (Embleton and Jones, unpublished). Sustained use of rather high rates of nitrogen from sodium nitrate resulted in a decline of Valencia orange trees growing on deep Lakeland fine sand in Florida; this decline was associated with an accumulation of excessive amounts of sodium in the trees (Smith, 1962*b*).

In greenhouse studies with a Yolo loam in 3-gallon pots, leaf burn and growth reduction of citrus seedlings was associated with exchangeable sodium in the soil of 7 per cent or more of the exchange complex (Martin, Harding, and Murphy, 1953).

However, most adverse effects of sodium on trees can be attributed to indirect effects on the soil. This is discussed in the next section (see p. 149).

Lithium

Lithium is not recognized as an essential element for plant growth, but it can be toxic to commercial citrus. In the field, toxicity for orange,

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lemon, and grapefruit, was associated with lithium concentrations of approximately 12 ppm or higher in the leaves (Aldrich, Vanselow, and Bradford, 1951). In greenhouse soil cultures, Bingham, Page, and Bradford (1964) found 180 ppm of lithium in leaf blades of sour orange to be associated with a 25 per cent growth reduction; for leaves of sour orange seedlings they listed less than 5 ppm as normal, 50 to 75 ppm as high, and 100 to 300 ppm as toxic. Hilgeman *et al.* (1970) associated 50 to 60 ppm of lithium in September leaf samples with the toxicity in old grapefruit trees in the Salt River Valley in Arizona. Additional research is needed to clarify the discrepancy in leaf levels associated with the toxicity.

Bradford (1961) reported toxic symptoms attributed at least in part to excess lithium in approximately 5 per cent of the citrus acreage of southern California. Some of the most severely affected orchards were in recently-developed desert areas where concentrations of lithium in newly-developed water wells were high. Bradford (1963) also reported that toxic lithium levels, capable of adversely affecting citrus growth were found in 25 per cent of 400 water samples representative of water sources in California.

SOIL AMENDMENTS AND INDIRECT EFFECTS OF CARRIERS OF ESSENTIAL ELEMENTS

Many materials, including fertilizers, when added to an orchard soil, may influence tree performance through effects which are other than nutritional *per se*. Some of these effects will be discussed in this section.

Of primary importance is the structure of the soil. Good soil structure provides for adequate movement of water and air through it. In some soils, physical conditions remain good in spite of physical and chemical abuses; in others, development or maintenance of good structure is difficult even with good management practices. Where structure is a potential problem, the possible effects of fertilizers and soil amendments must be considered.

Adding organic matter to the soil is one means of improving its structural properties. This can be accomplished either by planting cover crops or by bringing in organic matter from outside sources, as discussed in Chapter 4. Structurally, the soil in the long-term fertilizer experiments on Washington navel oranges at the University of California Citrus Research Center, Riverside, was difficult to manage. Studies showed that use of manure resulted in a marked increase in penetration of irrigation water (Jones *et al.*, 1961; Lombard *et al.*, 1962; Parker and Jenny, 1945). There was a high positive correlation between net water intake into the soil and yield (Jones *et al.*, 1961).

Mineral salts also influence soil structure. In the same experiment at Riverside, California (Aldrich *et al.*, 1945; Harding and Ryan, 1961; Jones *et al.*, 1961; Lombard *et al.*, 1962), continuous use of ammonium sulfate and sodium nitrate resulted in a deterioration in soil structure, reduction in water infiltration, and an increase in soil salinity. Use of lime with ammonium sulfate substantially improved soil structure and water infiltration when compared with ammonium sulfate alone. Use of gypsum with sodium nitrate substantially improved soil structure and water infiltration when compared with sodium nitrate alone. Continuous use of calcium nitrate resulted in a greater water infiltration than did continuous use of urea, ammonium sulfate plus lime, or sodium nitrate plus gypsum. The study of Aldrich *et al.* (1945) suggested that low water penetration in the ammonium sulfate plots resulted from accumulation of ammonium ion in the exchange complex because of lack of nitrification at the low pH. The accumulation of ammonium ion dispersed the soil colloids. Their study suggested that low water penetration in the sodium nitrate plots resulted from an accumulation of sodium in the exchange complex and an unfavorable calcium-sodium ratio in the soils. Cahoon *et al.* (1963) showed that less soil mass in the orchard was wetted per irrigation in ammonium sulfate and sodium nitrate treatments than in the other nitrogen source treatments.

In laboratory studies, Martin and Richards (1959) showed that exchangeable ammonium substantially reduced hydraulic conductivity, and that this reduction was greater in a highly acid, Hanford sandy loam than in a base-saturated, Hanford sandy loam. Similar effects of less magnitude were observed in a Yolo sandy loam and Yolo loam. In the Hanford soil, hydraulic conductivity was markedly reduced with as little as 10 per cent of the exchange complex saturated with ammonium or 5 per cent with sodium.

After an orchard is established, little can be done to influence soil structure at the lower depths. As pointed out in Chapter 4, most soil-management practices affect only the surface layer of soil.

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Over a period of time, some fertilizers, particularly the ammoniacal nitrogen materials, may have an important effect on soil reaction, the significance of which is discussed in Chapter 4. Addition of any material which results in a net reduction of the exchangeable basic cations in the soil will reduce soil pH. The ammonium ion from ammoniacal fertilizers replaces some of the calcium, magnesium, sodium, and potassium in the exchange complex, and after nitrification of the ammonium ion, nitric acid is formed. The net result is that some basic cations in the exchange complex are replaced by hydrogen ions, making the soil more acid.

The pH of a soil with a low cation-exchange capacity can be changed more rapidly with a residually acid fertilizer than a soil with a high cation-exchange capacity. Urea, ammonium nitrate, and anhydrous ammonia are residually acid fertilizers, but their effects per pound of nitrogen supplied are not as great as those of ammonium sulfate and ammonium phosphate.

Rassmussen and Smith (1959) and Spencer (1963) showed that ordinary and triple superphosphate had a strong temporary acidifying effect on Lakeland fine sand. Spencer (1963) demonstrated that the acidity developed from these fertilizers was not harmful to citrus growing in Lakeland fine sand if soil copper was low. If soil copper was high, copper toxicity developed from the increased acidity.

Sulfur is oxidized in the soil by the microorganisms, resulting in formation of sulfuric acid and an increase in soil acidity. Pest control and fertilizer programs frequently include large quantities of sulfur materials (Rasmussen and Smith, 1958), residues from which result in an increase in soil acidity. Sulfur has been applied to alkaline citrus soils to reduce alkalinity; however, beneficial results from this practice have not been observed. On the contrary, detrimental effects resulted when soil acidity was great enough to restrict development of soil microflora. Also, sulfur additions increased soil salt concentrations (Aldrich, 1949).

Continuous use of sodium nitrate resulted in an increase in soil pH (Pratt *et al.*, 1959). Adverse effects from sodium nitrate are greater on alkaline than on acid soils, but this material is used only on acid soils.

Lime is commonly used to control the pH of acid soils. Gypsum, when used to maintain structure of alkaline soils, has little if any influence on soil reaction. It is used as a calcium source to replace exchangeable sodium, which forms soluble sodium salts and can be more readily leached from the soil. The calcium from calcium nitrate functions the same as calcium from gypsum.

Experiments in Florida demonstrated that application of large amounts of gypsum to Lakeland fine sands as a soluble source of calcium was not a sound practice (Anderson, 1968). Such applications adversely affected tree growth and yield of oranges by inducing excessive levels of sulfur in the trees. In one experiment, 1.43 per cent of sulfur was observed in the leaves.

Liming practice and soil calcium additions may have striking effects on tree growth and yield. A factorial experiment in Florida on a fine-textured acid sand involving a pH range of 4.0 to 7.0 and annual calcium additions of between 0 and 400 pounds produced slow growth and low yield of Valencia orange trees at low pH and calcium levels, but excellent growth and yield at high pH and calcium levels (Anderson, 1972).

CITRUS YIELDS AS RELATED TO AMOUNTS, SOURCES, TIMING, AND METHODS OF FERTILIZATION

Nitrogen

Of all the essential elements, nitrogen supplements are most commonly required to maintain citrus yields. A review of recent fertilizer recommendations shows that nitrogen has been found advantageous or recommended in Australia (Bouma, 1959), the Belgian Congo (Philipp, 1958), Brazil (Rodriguez and Moreira, 1969), India (Singh, 1960), Israel (Heymann-Herschberg, 1956), Jamaica (Hewett, 1953), Japan (Kajiura, 1967), New Zealand (Fletcher, 1959), Philippine Islands (Felizardo, Galvez, and Davide, 1961), South Africa (Langenegger, 1958; Rosselet, Helff, and Langenegger, 1963), Spain (Rapallo, 1956), Arizona (Rodney and Sharples, 1961; Sharples and Hilgeman, 1969), California (Parker and Jones, 1951; Jones and Embleton, 1960*a*), Florida (Reitz *et al.*, 1972), and Texas (Maxwell and Dacus, 1958; Leyden, 1966). In most cases, these recommendations are based at least on a minimum of experimentation, but in some only on recognition of typical symptoms of nitrogen deficiency.

In spite of the interest in and importance of nitrogen application in citrus production, no uniform basis has heretofore been established for making such applications. Rates have varied widely, as have timing programs (Aldrich and

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Taylor, 1954; Heymann-Herschberg, 1956; Koo, Reitz, and Sites, 1958). Standardization is now being achieved in many citrus-growing regions of the world by leaf analysis (see chap. 6).

Some soils naturally contain sufficient nitrogen to maintain yields for an extended period, or sufficient nitrogen is found in irrigation water to support the trees. Nitrogen fertilization of a highly organic soil in southeastern Florida initially gave no increase in yield (Young and Forsee, 1949), but more recently trees in the same area have shown typical nitrogen deficiency symptoms and probably are responding favorably to the nitrogen fertilization now commercially practiced.

Nitrogen from long-continued, liberal, or excessive applications may accumulate in soils, particularly under a combination of dry climatic conditions and fine soil texture (Harding, 1954). No response to nitrogen fertilization might be obtained in such a case for several years after cessation of nitrogen fertilization (Jones and Embleton, 1954*a*; Jones *et al.*, 1959; Wallace *et al.*, 1952). After passage of a period of years, however, trees would again respond to nitrogen fertilization (Embleton *et al.*, 1959; Jones *et al.*, 1959).

Trees affected by disease or a variety of other limiting factors may also fail to respond to nitrogen fertilization. Certain cultural practices, such as clean cultivation, may delay yield response to nitrogen, whereas sod culture would hasten it (Bouma, 1959; Maxwell and Dacus, 1958).

However, nitrogen applications are almost always necessary for maintenance of citrus-tree yields. The problem is to achieve an adequate and economically-sound nutritional level. The amount used and manner of its application should prevent nitrogen from limiting yield. Effects on fruit quality and size, on soil physical conditions, and on nitrate contributions to underground waters should be considered. Variations in soils, climate, and cultural operations preclude a general recommendation applicable to all situations.

Amounts and Sources.—Yields can be severely limited by a lack of nitrogen. In an Australian experiment, extremely nitrogen-deficient Washington navel orange trees yielded only 25 per cent as much fruit as those with an optimum level of nitrogen (Bouma, 1956). In California, greatly reduced Washington navel yields were obtained from trees receiving no nitrogen compared with those given 0.5 pounds or more per tree annually (Parker and Batchelor, 1942). In the latter experiment, leaves of trees not receiving nitrogen showed the characteristic yellow color of deficiency, and the twigs died back, leaving the tree in an unthrifty condition.

The first increment of nitrogen added to deficient trees results in a greater increase in yield than additional increments. In Florida, yields of Pineapple and Valencia orange trees on Lakeland fine sand were increased by nitrogen applications up to approximately 100 pounds per acre annually, but produced little additional fruit when fertilized with either 200 or 350 pounds per acre. Leaves from trees receiving 50 pounds per acre of nitrogen were yellow much of the time and contained less than 2.3 per cent nitrogen. Leaves from trees receiving a 100-pound rate were slightly yellow during the period of fruit maturation, and contained about 2.3 per cent nitrogen, but yield was equal to that of trees receiving somewhat higher rates (Stewart *et al.*, 1961; Stewart and Wheaton, 1965).

Maximum yield of twelve-year-old Hamlin orange trees on rough lemon rootstock in central Florida was obtained with application rates of 1.8 pounds of nitrogen per tree and a leaf nitrogen percentage of 2.4 (Sites, Wander, and Deszyck, 1953). On seven-year-old Valencia orange trees on rough lemon rootstock in central Florida, nitrogen rates of 0.6, 1.2, and 2.4 pounds per tree resulted in 80, 111, and 138 pounds of fruit per tree, respectively, and percentages of nitrogen in leaves of 2.16, 2.33, and 2.54, respectively (Reuther and Smith, 1950). A continuation of this experiment with nitrogen rates increased to 0.75, 1.5, and 3.0 pounds per tree resulted in 281, 364, and 409 pounds of fruit per tree, respectively, with leaf nitrogen percentages in a December sample from spring-cycle, fruiting terminals of 2.30, 2.48, and 2.65, respectively (Reuther and Smith, 1952*b*). A more recent experiment with Valencia orange on acid sands in central Florida showed a definite increase in yield, with annual nitrogen rates up to 195 pounds per acre and a hint of yield increase up to 300 pounds. Nitrogen in four- to six-month-old leaves from nonfruiting shoots averaged 2.71 per cent for the 150-pound rate and increased in the range of 2.78 to 2.84 per cent for the 195- to 330-pound rates (Smith, 1967*a*). Another Valencia experiment in central Florida showed no significant yield difference over a seven-year period with average nitrogen rates of 1.7 and 3.4 pounds per tree and leaf nitrogen percentages averaging 2.72 and 2.96, respectively, in five-month-old leaves from non-

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fruiting shoots (Reuther *et al.*, 1957). Another experiment in central Florida showed an increase in Valencia orange yield up to 240 pounds per acre with mean leaf nitrogen varying from 2.77 per cent for the 150-pound rate to 2.91 per cent for the 330-pound rate (Smith, 1967*c*). One more Florida experiment, with Pineapple oranges growing in Lakeland fine sand, showed that, with half the nitrogen applied in October and the other half in May, an annual rate of 2 pounds per tree produced less fruit than 3 pounds per tree during the first five years of the experiment, and 2.5 pounds of nitrogen per tree produced less fruit than the 3.5 pound rate during the last five years of the experiment. For the latter five-year period, the mean percentage of nitrogen in four- to five-month-old leaves was 2.67 for the 2.5 pound rate and 2.77 for the 3.5 pound rate (Smith, Scudder, and Hrnciar, 1968). Smith (1971) showed that a low rate of 1.1 to 1.6 pounds of nitrogen per tree annually applied to Valencia oranges in central Florida produced slightly but significantly less fruit than a higher rate of 1.5 to 2.0 pounds in the seventh to thirteenth year after planting. The mean nitrogen concentrations in four- to five-month-old leaves from nonfruiting terminals, where timing of application was also a variable, was 2.65 per cent for the low rate and 2.73 for the high rate.

Yields of navel orange trees in the San Joaquin Valley of California were increased very little, if any, by application rates higher than 0.5 pounds per tree; rates as high as 4 pounds per tree did not result in increased production (Jones *et al.*, 1959; Jones and Embleton, 1967). On the Yuma Mesa in Arizona, 1 pound of nitrogen per tree annually applied to thirteen-year-old Valencia orange trees resulted in 2.20 per cent nitrogen in July leaf samples from nonfruiting terminals, and yields were less than those from the 2-, 3-, and 4-pound rates where the percentage of nitrogen in leaves was above 2.3 per cent (Rodney, 1964). A later report from the Yuma area stated the highest yields were obtained from 3 pounds of nitrogen per tree annually, with an average leaf analysis of 2.53 per cent nitrogen in spring-flush Valencia orange leaves sampled in July; leaf values below 2.2 per cent were consistently associated with reduced yields (Rodney, 1969).

In the Salt River Valley in Arizona, calculations from regression coefficients from data of a nine-year experiment with Valencia oranges growing in a calcareous, sandy loam soil, indicated that optimum yields were associated with nitrogen percentages of from 2.15 to 2.27 in six-month-old, spring-cycle leaves from nonfruiting shoots, with a mean of 2.21. The optimum yield was associated with 1.3 pounds of nitrogen per tree annually. Nitrogen rates up to 8.0 pounds did not increase yields above the 1.3 rate, but increased the percentage of nitrogen in leaves up to a mean of 2.3 (Sharples and Hilgeman, 1969).

Yields of Shamouti oranges in Israel on sour orange rootstock were equal at nitrogen-application rates of approximately 100, 200, or 300 pounds per acre (Oppenheimer and Heymann-Herschberg, 1954).

Along Florida's east coast, in loamy fine sands typical of Florida "hammock" conditions, an application rate of 1.2 pounds of nitrogen per Valencia orange tree resulted in distinct signs of nitrogen deficiency in slightly over half of the trees in the plots, and the leaves contained about 2.0 per cent of nitrogen. Under these conditions, yield was reduced by 25 per cent compared with the 2.4- and 4.8-pound rates. For the three rates, the percentage of nitrogen in the leaves was 2.10, 2.25, and 2.35 (Reitz and Koo, 1960). Another experiment in eastern Florida on Wabasso fine sand (formerly classified as Leon fine sand) showed that twelve- to fifteen-year-old Temple orange trees on the low ammonium nitrate rate (35 to 46 pounds of nitrogen per acre annually) produced significantly less fruit than did those on either the medium rate (77 to 93 pounds of nitrogen) or high rate (186 to 246 pounds of nitrogen). Yields from those at the high rate were numerically, but not significantly, higher than those at the medium rate. Nitrogen concentrations in spring-flush leaves from nonbearing twigs sampled in the July to August period averaged 2.28 per cent at the low rate, 2.38 per cent at the medium rate, and 2.37 per cent at the high rate (Calvert, 1970).

Yields of three varieties of orange trees in Australia were increased by nitrogen fertilization at the rate of 0.8 pound of nitrogen (from ammonium sulfate) per tree compared with no nitrogen under nontilled, bare-surface culture and sod-culture conditions. Application rates higher than this failed to further increase yield significantly. At 3.2 pounds of nitrogen per tree, a decrease in yield occurred under some cultural conditions where phosphorus was limiting. Good yield was usually attained if leaves contained over 2.5 per cent of nitrogen (Bouma, 1959). In Egypt, orange yields for the first eight years of production were increased by annual rates up to $\frac{1}{8}$ pound of nitrogen

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for each year of age of the trees, while mandarin yields were increased by rates up to ⅛ pound of nitrogen for each year of age (El-Mahmoudi, 1959).

Grapefruit leaves generally contain a lower nitrogen concentration than do orange leaves of trees grown under comparable conditions (Heymann-Herschberg, 1956; Reitz and Long, 1952). Complete withholding of nitrogen fertilization from Marsh grapefruit trees on sour orange rootstock in the Indian River district of Florida resulted in a leaf nitrogen content of 1.70 per cent and 4.9 boxes (440 pounds) per tree, which was about half that obtained from the 2-pound rate, with an associated leaf nitrogen percentage of 2.13. Most, if not all, of the trees in the no-nitrogen treatment showed distinct symptoms of nitrogen deficiency throughout the year. Trees receiving 1 pound of nitrogen per tree also showed slight symptoms of nitrogen deficiency upon occasion, and yield of these trees also was somewhat reduced; leaf nitrogen percentage for this rate averaged 1.93 (Reitz and Hunziker, 1961). Preliminary information from experiments on desert grapefruit on sandy soils in California indicated that an annual rate of about 3 pounds of nitrogen per mature tree was needed to maintain maximum yield; maximum yield was associated with 2.0 to 2.2 per cent nitrogen in five- to seven-month-old, spring-cycle leaves from nonfruiting shoots (Jones and Embleton, 1968).

Florida yields of Marsh grapefruit on rough lemon rootstock on acid sands were statistically equal at application rates of 120, 240, and 540 pounds of nitrogen per acre, giving leaf analyses of from 2.30 to 2.79 per cent nitrogen (Smith and Rasmussen, 1961*b*). Another Florida experiment, with young Marsh grapefruit trees planted in acid sands, suggested a yield increase with the use of up to 2.4 pounds of nitrogen per tree annually (Smith, 1966). Over a six-year period, significant increases in grapefruit yield were obtained in central Florida with the use of up to 2.0 pounds of nitrogen per tree, with an associated mean percentage of nitrogen of 2.4 in four- to five-month-old, spring-cycle leaves from nonfruiting shoots (Smith, 1969*a*).

Increasing the percentage of nitrogen in the applied fertilizer mixture from 2 to 4 to 6 increased yields of Persian limes growing in an oolitic limestone soil in southern Florida. The increase in yield was more apparent when nitrogen was applied in conjunction with phosphorus and potassium (Goldweber, Boss, and Lynch, 1956). Yields of Persian limes growing on Lakeland fine sand were increased by rates of nitrogen up to 4.9 pounds per tree annually. The nitrogen concentration in spring-cycle leaves sampled in the fall ranged from 2.25 per cent for the 1.5-pound rate to 2.59 for the 4.9-pound rate (Young and Koo, 1967). Tahiti (Persian) lime yields, on a Rockdale fine sandy loam-limestone complex (oolitic limestone) soil in southern Florida, were increased with increasing nitrogen rates up to 262 pounds per acre (1.6 pounds per tree) annually. Higher rates were not included in the experiment (Campbell and Orth, 1968).

Jones and Embleton (1964) and Jones *et al.* (1970) reported that no consistent increase in lemon yield had been observed by increasing the nitrogen percentage above 2.5 per cent in the most recently fully-matured terminal leaves from nonfruiting shoots sampled in August. The specific age of such lemon leaves cannot be readily determined (Embleton *et al.*, 1969). A similar problem exists in limes (Campbell and Orth, 1968). However, on the more vigorous lemon selections, it was not possible to attain the 2.5 per cent level in the leaves, even with uneconomically high rates of nitrogen. Therefore, for Prior Lisbon and more vigorous cultivars, 2.0 per cent was suggested as a practical and economic level. Chapman, Joseph, and Rayner (1969) reported that, for Monroe Lisbon lemons growing in out-of-door concrete water cultures, 2.25 to 2.40 per cent nitrogen in mature or recently mature leaves from nonfruiting, nonblossom and nonflush bearing terminals in July, August, or September would be appropriate levels for maximum fruit production.

A considerable range in optimum application rates has been shown under the variety of conditions where citrus is grown. Obviously, unless experiments are to be run on each set of circumstances, a common denominator for relating the tree's performance to its need for nitrogen fertilization is highly desirable. Leaf analysis appears to be that common demominator (see chap. 6). In the experiments just discussed, the nitrogen concentration in orange leaves above which no significant yield increase was observed was generally between 2.2 and 2.4 per cent. In some of the experiments in central Florida, there were exceptions in which higher concentrations of leaf nitrogen were needed to maintain full production. In grapefruit leaves, the nitrogen levels associated with a loss in production appear to be somewhat lower than those for oranges.

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Unfortunately, lack of standardization of leaf-sampling methods makes it virtually impossible to compare, with a desirable degree of precision, the results from several of the fairly precise experiments run under a variety of conditions. Studies by Harding, Ryan, and Bradford (1962) and Embleton *et al.* (1963) showed that wide differences in nitrogen content of orange leaves are associated with sampling methods, and that leaves from fruiting and nonfruiting terminals cannot be interpreted by the same standards. Jones and Embleton (1960*a*) established commercial standards for nitrogen levels in spring-cycle orange leaves from nonfruiting terminals sampled in California in the mid-August to mid-October period. Reitz *et al.* (1972) suggested leaf analysis standards for nonfruiting terminals for central Florida conditions. Chapman (1960) reported standards for 4- to 10-month-old, spring-cycle leaves from fruit-bearing terminals. DeVilliers (1969) reported revised leaf analysis standards for South African conditions for leaves from fruiting shoots.

Appreciable overuse of nitrogen in the economic sense under many conditions does not appear to directly limit the productivity of citrus, although indirect effects may be important. The range of effective and tolerable application rates is broad, reportedly, in pounds of nitrogen per tree annually, from 0.8 to 3.2 in Australia, 0.5 to 5.0 in California, and, in pounds per acre, from 120 to 540 in Florida and from 100 to 300 in Israel. However, application rates of nitrogen that result in maximum yield or rates higher than these may result in deterioration of exterior fruit quality, such as retention of green color, coarseness, and thickness of peel. Depending on the relative importance of the fresh fruit and processing fruit markets, this factor may or may not be important. In California, even as little nitrogen as 0.5 to 1 pound per tree increased peel thickness and reduced juice content of the fruit compared to no nitrogen, but to a degree considered tolerable in the market. A rate of 1 pound was suggested in the interest of maintaining yield and good fruit quality (Jones *et al.*, 1959). In Florida, where the processing outlet often is as profitable to growers as the fresh fruit outlet, higher rates are recommended (Reitz *et al.*, 1972), even though some of the same effects on fruit quality are noted as in California.

Under conditions of commercial citrus production, over-fertilization with nitrogen of the varieties studied apparently does not induce excess vegetativeness to the extent that fruit set is impaired. Under many conditions, high nitrogen rates have maintained yield, but in others the development of a number of unfavorable soil conditions, usually related to the nitrogen source or salt concentration effect, have brought about yield declines. In these cases, the effects seem to be indirect.

In South Africa, some loss of yield occurred in the later years of a twenty-year experiment when pH in the first foot of soil in ammonium sulfate plots dropped below 4.5 (Rosselet *et al.*, 1963).

In California, long-continued use of sodium nitrate as a nitrogen source eventually led to deleterious effects on soil structure (Parker and Jones, 1951), thus retarding water intake and permitting the accumulation of a deleterious amount of salt (Jones *et al.*, 1961; Harding, Pratt, and Jones, 1958). In the same experiment, long-continued use of ammonium sulfate also led to deleterious effects on soil structure, retarded intake of irrigation water, and lowered pH. Under both conditions, yield declined to approximately that of trees receiving no nitrogen and was substantially lower than the yield of trees receiving nitrogen from other sources. The onset of these effects was doubtlessly accelerated by the use of unnecessarily high application rates, although it is probable that the same effects would have developed at a somewhat slower pace even if lower application rates had been used.

In the essentially single-grained structure of central Florida's fine sandy soils, which are extensively planted to citrus, excessive nitrogen rates have brought about declines in yields of both oranges and grapefruit. In one experiment (Stewart *et al.*, 1961), the yield of Pineapple oranges on rough lemon rootstock was no higher from 550 pounds of nitrogen per acre than from 50 pounds. Intermediate rates increased yield compared with either of the extremes. Sodium nitrate was less detrimental to yield at high rates than was ammonium nitrate. In another experiment (Sites, Wander, and Deszyck, 1961), the yield of Duncan grapefruit on rough lemon rootstock was reduced from a maximum of nine boxes (765 pounds) per tree at 230 pounds of nitrogen per acre to a minimum of 7.7 boxes (655 pounds) per tree when 575 pounds of nitrogen were applied in the form of ammonium nitrate. In central Florida, Smith (1967*c*) and Smith *et al.* (1968) showed little, if any, difference in orange yield between ammonium nitrate and anhydrous am-

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monia, but yields declined where sodium nitrate was used at the higher rates. Even in fine-textured soils of the Indian River area, a slight decline in Marsh grapefruit production was reported when application rates were increased from the optimum of 2 pounds per tree to a maximum of 4 pounds in the form of sodium nitrate (Reitz and Hunziker, 1961). Possibly sodium toxicity was a factor where high rates of sodium nitrate were used (Smith, 1962*b*).

In these cases and others, even where no decline in yield has been recorded, a deterioration of the root system of trees receiving high nitrogen has been reported (Ford, 1957). Conceivably, deterioration was due to the effect of soluble salts, but under the moderately high rainfall conditions of central Florida, this theory has received little support. A more plausible theory under old-grove conditions in central Florida is that high rates of application of acid-forming fertilizer materials (ammoniacal nitrogen sources) have lowered soil pH, perhaps drastically in the immediate vicinity of the fertilizer particles, thus rendering more soluble and mobile—and hence more toxic—the copper accumulated in the soil over many years of more than adequate application of this element (Spencer, 1963). Credence is given indirectly to this theory by the fact that in another experiment, under similar climatic conditions, application rates of 550 pounds of nitrogen per acre did not bring about a decline in production of young but heavily bearing grapefruit trees in which a high concentration of soil copper had not been developed (Smith and Rasmussen, 1961*b*).

In Australia, yield of Washington navel orange trees on sour orange rootstock was decreased slightly by applications of 3.2 pounds of nitrogen per tree as ammonium sulfate when compared with rates of 1.6 pounds. In this case, a decrease in soil pH due to the effect of the nitrogen source was thought to have reduced availability of an already marginal phosphorus supply to such an extent that phosphorus deficiency became the limiting factor (Bouma, 1960).

Obviously the use of excessive amounts of nitrogenous materials may not be simply innocuously wasteful. Detrimental effects in the form of soil structure deterioration, salt accumulation, and lower soil pH, with its attendant effect upon availability or toxicity of other soil-contained elements, are some of the factors to be considered in long-range evaluation of fertilizer practices.

Timing of Application.—Evidence shows that the period in which a shortage of nitrogen in mature, bearing citrus trees can be most critical is just prior to and during the blossoming, fruit-setting, and "June drop" (Chapman and Parker, 1942). In young trees, a continuing rapid increase in tree size requires high nitrogen nutrition throughout the entire growing season.

The effect of timing of nitrogen applications on yield has been studied under a variety of conditions. In many experiments, the application rates studied were rather high, so that levels of nitrogen nutrition attained in all treatments throughout the year were within the broad area adequate for yield maintenance. Under such conditions, the effects of a variety of timing programs for nitrogen have been rather slight and of little consequence from the practical standpoint.

In central Florida, where soils are sandy and rainfall is high, Reuther *et al.* (1957) showed that in a seven-year period there was no consistent effect of various timings of nitrogen application on yield of Valencia oranges where an average of 1.7 or 3.4 pounds of nitrogen was applied per tree annually. Reuther and Smith (1954) showed, from experiments in central Florida on Parson Brown, Hamlin, and Valencia oranges, that an annual dosage of nitrogen in one application in October or March was as effective as applying the same amounts of nitrogen in three or six applications per year. In another Valencia orange experiment in central Florida, where the low rate of from 1.1 to 1.6 pounds of nitrogen per tree annually produced slightly more fruit than 1.5 to 2.0 pounds of nitrogen in the seventh to thirteenth year after planting, applying all the nitrogen in February, July, or October resulted in equal yields (Smith, 1971).

In Texas, where annual rates of 3 pounds of nitrogen per Ruby Red grapefruit tree produced more fruit than 1 pound per tree, there was no difference between one, two, or three applications per year (Maxwell and Dacus, 1958). Over a seven-year period in Florida's Indian River area, on a calcareous hammock soil, equal annual rates of a mixed fertilizer were applied in February, February and June, May, May and October, October, June and December, or February, June, and November; they had no statistically significant effect on Valencia orange yield, however, but at certain times of the year tree and fruit character differences were observed (Reitz, 1956). A continuation of this study showed that annual applications of 6.25 pounds per tree of an 8–4–10–4

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fertilizer produced less fruit than 25 pounds of the same fertilizer mix, but there was no significant yield difference among applications in February or June or November or split equally between June and November (Calvert and Reitz, 1964).

A Valencia orange experiment in Argentina showed that significantly more fruit was produced with an annual per tree rate of 2.2 pounds of nitrogen than with 1.1 pounds, but applying these rates in one, two or three applications per year had no significant effect (Aso and Stein, 1967). Embleton, Jones, and Platt (1969) summarized results from a number of California experiments on orange, grapefruit and lemon. In no case did yields from winter applications of nitrogen differ from the same annual rates applied part in winter and part at other times of the year for the total period for each experiment, even though varying annual nitrogen rates significantly affected yields in some experiments.

In other experiments, the rate of nitrogen application and cultural management was such that trees were somewhat deficient in nitrogen at certain times of the year. Under these conditions, effects of nitrogen timing are of considerable importance. A high nitrogen level in winter was shown to be essential for maximum production of grapefruit in Arizona (Martin, 1939*a*, 1939*b*). Yield was little affected whether nitrogen subsequently was held at high or low levels during the spring and summer. In contrast, when the nitrogen level was held low in winter, yield was low regardless of whether the nitrogen level remained low or high in spring and summer. From the standpoint of fresh fruit production, a high proportion of top-grade fruit was associated with low nitrogen during the fall, but not necessarily associated with nitrogen level during the winter and spring. On Valencia oranges in Texas (Leyden, 1966), an annual December or January application of 1 or 2 pounds of nitrogen resulted in higher yields than a February application. In a nine-year experiment on grapefruit on a deep, sandy soil in central Florida, annual rates of nitrogen up to 3 pounds per tree increased yields. During the last three years, rates of 1.0, 1.5 and 2.0 pounds per tree applied in July produced less fruit than the same rates applied in October; at the 3.0 pound rate yields were not affected by timing of application (Smith, 1969*a*; Smith, Scudder, and Hrnciar, 1969). Timing can affect fruit quality in the absence of an effect on yield (Jones and Embleton, 1960*b*).

The question of the importance of nitrogen timing must be resolved on the basis of whether the appearance and grade of fruit is important to its economic value. If so, timing of minimum nitrogen rates may be of considerable importance in the operation's economic outcome. Careful control of nitrogen levels at various periods of the year will contribute significantly to success. In this respect, leaf analysis and close observation of visual symptoms may be the best combination of criteria available. On the other hand, if appearance and grade of fruit are of no particular consequence to returns obtained, such as with fruit produced primarily for processing, it may be simpler and more prudent to maintain nitrogen content of trees at a reasonably high level throughout the year.

Methods of Application.—Within wide limits, citrus trees are tolerant of a great diversity of application methods for fertilizer materials. At a rate of 3 pounds of nitrogen per tree annually, even as wide a divergence as applying all fertilizer in the cultivated areas between trees (about a 16-foot swath between tree rows that were 24 feet apart), compared with applying all of it beneath the trees, was of little consequence so far as yields were concerned (Jones and Cree, 1953). However, Smith (1967*c*) and Smith *et al.* (1968) showed that, under central Florida conditions with orange trees growing in fine sand and with 30 feet between tree rows, application of nitrogen to a 14- to 16-foot swath of the row middle was not as effective as applying it in a 21-foot swath in the row middles or a full spread covering the whole orchard floor. The 21-foot swath was as effective as the full coverage; thus, full coverage was not essential.

Successful application methods include use of ammonia or other soluble nitrogen materials in irrigation water, application as simple nitrogen salts or their solutions directly to the soil by mechanical spreaders of a variety of types, application in mixed fertilizers by drill-type or centrifugal spreaders, application by means of foliage sprays with low-biuret urea as the source, and application by aircraft. Choice of method depends primarily on economic factors in conjunction with the necessity of insuring effective uptake of the applied nitrogen at the time necessary for proper tree nutrition. Indirect effects appear to be associated with some of the application methods, but specific information is lacking in this regard.

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Phosphorus

In only a small part of the world's citrus orchards has phosphorus application resulted in an increase in tree growth and yield. Wherever found, phosphorus deficiency has been readily overcome by an application of a variety of organic or inorganic phosphatic materials to the soil. Nonetheless, phosphorus has been used to some extent in most citrus areas, perhaps on the unjustified assumption that citrus would respond to phosphorus wherever annual crops responded.

Leaf and soil analysis surveys have been made in a number of areas to explore the possibility that phosphorus was in limiting supply. In California, survey data are in general agreement that phosphorus fertilization would increase yield in only a small proportion of orchards (Chapman and Fullmer, 1951; Harding, 1953; Pratt *et al.*, 1956). As would be expected from the ample evidence showing accumulation of available phosphorus in soils in Florida, a leaf-analysis survey showed a high level of phosphorus nutrition in the Florida Valencia orange (Koo *et al.*, 1958). Phosphorus status of the soil and leaves in twenty-six Valencia orange orchards in Australia's Murrumbidgee irrigation area was found to be somewhat higher than in an experimental orchard where phosphorus deficiency was indicated (Bouma, 1956). Evidence indicated that a low phosphorus level in commercial orchards might be detrimental to fruit quality. In Israel, phosphorus in leaves was considered to be relatively high (Heymann-Herschberg, 1956). These examples represent the most common status of phosphorus requirement in citrus areas.

However, citrus phosphorus deficiency has been reported in field experiments in a few areas of the world, including the following: South Africa (Allwright, 1938; Anderssen, 1947); organic soils in Florida (Young and Forsee, 1949) and some highly leached sands in Florida (Anderson, 1966; Smith and Rasmussen, 1958; Spencer, 1963); Jamaica (Innes, 1946); Australia (Bouma, 1959); Japan (Tasaki, Inove, and Matsouka, 1930); California (Aldrich and Coony, 1952; Embleton *et al.*, 1967; Embleton, Kirkpatrick, and Parker, 1952); Israel (Bar-Akiva, Shaked, and Sagiv, 1967; and Arizona (Rodney and Sharples, 1961).

Critical evaluations of phosphorus requirements of citrus trees in a number of areas are now available. Because of the diversity of phosphorus usage, a review follows of experiences in several producing areas.

Phosphorus Use in Florida.—Phosphorus use in Florida probably began with the advent of the first use of mixed fertilizers. Until about 1932, use of phosphorus in fertilizers was virtually universal in young and old orchards alike. This frequent application was first questioned by Bryan (1933), who showed in pot cultures that, on the acid, sandy soils commonly planted to citrus in central Florida, phosphorus tended to accumulate in forms available to a variety of crops. Bryan's view gained acceptance very slowly, however, and even in recent years, considerable numbers of growers applied phosphorus in old orchards (Koo *et al.*, 1958).

Little critical evidence exists to show that annual phosphorus fertilization in Florida is necessary for good citrus yields. Phosphorus applications failed to increase yield of Pineapple oranges planted in a soil never previously fertilized in one location in Lake County and in a mature Valencia orange orchard on Lakeland soil in Pinellas County (Reuther *et al.*, 1949). Yields of Valencia oranges growing on a Lakeland fine sand were increased in some but not all years by phosphorus applications. In these experiments, initial leaf analysis indicated low phosphorus and, in fact, no phosphorus had been applied for at least five years prior to establishing the experiments (Spencer, 1963; Anderson, 1966). Phosphorus was clearly shown to be deficient in Lue Gim Gong orange trees on a high organic soil (Davie mucky fine sand) in Broward County (Young and Forsee, 1949). Also, phosphorus use increased growth of young orange trees on a Lakewood sand in Pasco County (Smith and Rasmussen, 1958), and in a block of young Pineapple orange trees in Polk County on Lakeland fine sand; it increased both yield and tree growth in a young Hamlin orange orchard on Lakeland soil in Polk County (Spencer, 1963). Citrus plantings on Lakewood soil series and on Davie soil series are limited in Florida, and hence these must be considered somewhat exceptional cases. Since enhanced growth of young trees in three locations and some yield increase in one location with an unknown past fertilizer history have been reported on Lakeland sand, perhaps the soil series most extensively planted to citrus in Florida, suggests that other locations not now suffering from phosphorus deficiency would have exhibited such symptoms except for the practically universal use of phosphorus in young tree fertilizers in Florida in the past.

Low phosphorus rates increased growth of young, nonbearing trees in two out of five experi-

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ments on flatwoods soils; higher phosphorus rates were no better than the lower ones (Anderson and Calvert, 1967).

Use of high rates of phosphorus application under certain conditions is not merely wasteful of resources, but also brings about some undesirable effects. Poor fruit quality in terms of lower soluble solids in juice or tendency toward greener peel color has been reported in phosphorus experiments (see discussion on fruit quality, p. 167). Lower root concentration and apparent root injury have been noted in several locations after high phosphorus use (Smith, 1956; Ford, 1957; Spencer, 1958, 1960). These have been attributed to mobilization of soil copper by the acidity of the phosphorus-containing materials, with consequent copper-toxicity development (Spencer, 1963). Where copper has not accumulated in the soil or soil is high in organic matter, copper deficiency in the form of severe fruit symptoms has been brought about in the field by phosphorus application. This deficiency, however, was readily overcome by application of copper-containing sprays to foliage (Young and Forsee, 1949). The uptake of other essential elements may be restricted by phosphorus fertilization (Spencer, 1960; Reuther, Gardner *et al.*, 1949).

There is little reason to believe that, under Florida conditions, the continuous use of phosphorus is required to maintain productivity of citrus trees after building up the native level somewhat by annual applications during the first four or five years after planting virgin soil. On the other hand, dangers due to overuse of phosphorus have been noted. Hence, it is important, through continuing study, to determine the status of soils and trees so that the nutritional level may be kept between the rather wide boundaries of deficiency and excess.

Both leaf and soil analyses are useful guides to phosphorus-fertilization needs of citrus trees. Leaf analysis is of particular value in indicating definite phosphorus deficiency, but it is less valuable in indicating soil reserves of phosphorus, since leaf phosphorus is not closely correlated with soil phosphorus at the higher soil-phosphorus levels (Koo *et al.*, 1958).

Low soil-phosphorus values correlate well with tree performance. Soil analyses give a measure of the soil-phosphorus supply at all soil-phosphorus levels. Soil-analysis values are reasonably constant over a period of years, and analysis of the soil may be performed on samples taken at any time (Spencer, 1963; Reitz *et al.*, 1972).

Phosphorus Use in California.—In contrast to practices in Florida, applications of inorganic phosphorus fertilizers to citrus in California have never been widespread, but manures have been widely used and have contributed to phosphorus accumulations in the soil. Well-laid-out experimental blocks failed, until recently, to demonstrate an increase in yield due to phosphorus applications in a variety of locations (Parker and Batchelor, 1942). Since 1949 a number of cases of phosphorus deficiency have been reported from southern California. Phosphorus applications to a Eureka lemon orchard on rough lemon rootstock, on gravelly, fine sandy loam in Ventura County, resulted in improved appearance of the trees and an increase in fruit set (Aldrich and Haas, 1949). Leaf symptoms of the deficiency were also observed. In subsequent reports, it was shown clearly that phosphorus applications increased yield of Eureka lemons in some cases in southern California. With application rates of 4.2 pounds of elemental phosphorus per lemon tree, appreciable yield increases were obtained by increasing the phosphorus percentage in leaves from the range of 0.06 to 0.08 up to 0.08 to 0.16 (Aldrich and Coony, 1952). Phosphorus deficiency of Eureka lemon was reported in Santa Barbara County (Embleton *et al.*, 1967). In a Valencia orange orchard on sour orange rootstock in Ramona stony sandy loam in San Diego County, application rates of 4 pounds of phosphorus per tree per year for three years resulted in significant increases in yield in three out of four successive years and increased leaf phosphorus from the 0.06 to 0.116 per cent range to the 0.112 to 0.140 per cent range (Embleton, Jones *et al.*, 1956; Embleton, Kirkpatrick *et al.*, 1956).

No doubt exists that, under some circumstances in California, yield increases can be obtained by application of phosphorus fertilizers. However, the occurrence of such responses does not constitute the common situation. Observation of symptoms as well as judicious use of leaf and soil analysis are useful means to determine the need for phosphorus in unusual situations (Embleton, Jones *et al.*, 1956; Embleton, Kirkpatrick *et al.*, 1956; Aldrich and Buchanan, 1954).

Very high phosphorus rates to mature Valencia orange trees reduced yields (Embleton *et al.*, 1971). Also, high phosphorus rates to soil cultures induced copper deficiency and reduced the concentration of zinc in the leaves (Bingham and Garber, 1960; Bingham and Martin, 1956; Martin and Van Gundy, 1963).

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Phosphorus Use in Arizona.—Increased citrus yield in Arizona has been reported in only one experiment, on young Lisbon lemon trees on rough lemon rootstock growing on a calcareous Superstition sand (Rodney and Sharples, 1961). During the fourth year in the orchard, trees receiving 0.87 pounds of phosphorus per tree per year produced from 10 to 28 per cent more fruit than trees not receiving phosphorus. Only when phosphorus was applied did trees respond to nitrogen application. The phosphrous content of leaves ranged from 0.131 to 0.223 per cent in July-picked, spring-flush leaves, but use of phosphorus did not bring about an increase in leaf phosphorus.

Phosphorus Use in Australia.—Phosphorus is recommended for use on citrus generally in South Australia. Part of the basis for this recommendation was obtained from a long-term experiment at the South Australian Irrigation Research Station, near Griffith (Bouma, 1959; Bouma and McIntyre, 1963). During the experiment, involving different nitrogen rates, nitrogen application had only a limited effect on yield until phosphorus was added. Prior to addition of phosphorus, yields were actually depressed by high nitrogen because of apparent low available phosphorus levels. Subsequently, Bouma (1960) showed that the low soil pH caused by higher rates of application of ammonium sulfate decreased soil phosphorus availability.

A survey showed that the soils in most commercial orchards of the area were higher in soil phosphorus than was the soil in the experimental area (Bouma, 1956). The reports upon this experiment did not indicate that soil analysis for phosphorus would prove to be particularly useful; however, considerable reliance was given to leaf analysis in interpreting the results.

Phosphorus Use in Israel.—The phosphorus status of Israeli soils planted to citrus has been studied by survey techniques and field experimentation (Heymann-Herschberg, 1952*a*, 1952*b*, 1956). In most orchard soils surveyed, phosphorus appeared to be relatively high. In field experiments, some apparent declines in yields have been obtained from phosphorus applications. These declines have been explained on the basis of reduced nitrogen absorption following phosphorus applications. A study by means of survey methods did not indicate that the combination of nitrogen plus phosphorus increased yield more than nitrogen alone. A study of low- and high-producing orchards showed no correlation between phosphorus and yield. Recently Bar-Akiva *et al.*, (1967) and Bar-Akiva, Hiller, and Patt (1968) reported a yield increase of Marsh grapefruit from phosphorus or manure applications.

Phosphorus Use in South Africa.—Phosphorus applications increased yield of citrus trees in three experiments in South Africa (Allwright, 1938; Rosselet *et al.*, 1962; DeVilliers, 1969). The phosphorus in South African soils is generally considered not readily available to plants. In most citrus-producing areas, phosphorus is recommended, except that in certain areas, such as the Sunday's River Valley, no beneficial effect of phosphorus fertilization has been shown (Naudé, 1954). Consequently, applications of 0.44 to 0.70 pound of phosphorus per tree per year are generally recommended for citrus production in much of South Africa (Langenegger, 1958).

Phosphorus Use in Jamaica.—Grapefruit yield has been reportedly increased by phosphorus applications at Wakefield (in St. Catherine) (Innes, 1946). In other locations, no increase in response to phosphorus fertilization has been obtained, and, in fact, slight decreases appeared to have resulted (Hewett, 1953).

Phosphorus Use in Brazil.—Rodriguez and Moreira (1969) confirmed previous observations that phosphorus can limit citrus production, at least in some Brazilian orchards. The Baianinha navel orange trees were planted in an acid soil in 1947; differential annual phosphorus rates were initiated in 1951. Favorable effects from phosphorus fertilization were observed in the following two-year periods: 1955–56, 1957–58, 1963–64, and 1965–66. The P_2 rate was 0.22 pounds of phosphorus per tree (from ordinary superphosphate) from 1951–52, 0.44 pounds from 1953–54, 0.66 from 1955–56, and 0.44 from 1957 on. The P_1 rate was half of the P_2 rate; the P_2 rate produced more fruit than the P_1 rate, and the P_1 rate more than the P_0.

General.—Several generalizations are apparent from the above review of the available literature. One is that phosphorus has been commonly applied in citrus orchards in many locations in the world, even though only a minimal amount of information justifying these applications in terms of economic returns has been available. In most cases, where a need for phosphorus has been demonstrated, the area involved is relatively small. Since detrimental effects on some factors of fruit quality and size as well as on root growth in certain cases have been noted following phos-

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phorus applications, critical study of the phosphorus status of trees in each specific locality is highly desirable. In this respect, leaf as well as soil analysis techniques have a place (see chaps. 4 and 6).

Potassium

Use of potassium has been reported from a considerable number of citrus-producing areas. In some cases, the reported use appears to be largely precautionary (Fletcher, 1959; Felizardo *et al.*, 1961), while in others, beneficial effects of potassium fertilization have been thoroughly documented, and usage is justified. It is primarily in the highly leached, low-potassium, acid soil areas that the need for potassium fertilization has been demonstrated.

Potassium requirements for maximum volume yield are satisfied at rather moderate potassium levels in the tree. However, at levels higher than those influencing numbers of fruit produced, additional changes in fruit size, and quality factors such as color, texture, and acidity of juice are brought about (see chap. 6, p. 189). Within this latter range, little change in appearance of trees is noted, although foliage of trees on high-potassium nutrition may be less dense than that of trees at near-deficient potassium levels due to effects on length of internodes and leaf size. Except at extremely deficient levels, leaf symptoms are of little or no assistance in determining the tree's nutritional status. Fruit quality may give some clues to nutritional status, but these symptoms are not sufficiently specific to make decisions about fertilizer practices. Leaf analysis does provide a good guide, and is currently being used commercially (Embleton and Jones, 1963; Embleton, Jones, and Platt, 1967; Willson and Arey, 1958).

On acid, sandy soils, a number of experiments have given similar results in relating potassium fertilization practices to performance of the trees. A number of these will be briefly reviewed.

In an early experiment, ten- to fifteen-year-old Valencia orange trees on rough lemon rootstock received no potassium, a medium rate of approximately 1.7 pounds, or a high annual rate of approximately 2.5 pounds potassium per tree (Bahrt and Roy, 1940). During the last four years of the five-year experiment, those trees not receiving potassium had about 0.9 per cent potassium in leaves and averaged 275 pounds of fruit per tree per year. Those receiving the medium or high application rates averaged between 1.3 and 1.7 per cent of potassium in leaves and produced between 300 and 350 pounds of fruit per tree annually.

In another experiment, five-year-old Valencia orange trees on rough lemon rootstock were given three rates of potassium fertilization: 0.21, 1.25, and 2.50 pounds of potassium per tree annually (Reuther and Smith, 1950, 1952*b*). Yield in the first year (1948–49) was very slightly increased by the high potassium level. The leaves from the low-potassium trees contained 1.30 per cent potassium, whereas the leaves from trees in the high-potassium plots contained 1.91 per cent potassium. Yields during 1949–51, however, were not significantly increased by continuation of the same treatments, although the difference in potassium level in leaves had been widened to 0.84, 1.47, and 1.72 per cent potassium in the three treatments.

In a third experiment, both Hamlin and Valencia oranges on rough lemon rootstocks, planted in 1937, were put under differential potassium treatments in 1939 and continued under those treatments for fifteen years (Deszyck, Koo, and Ting, 1958; Sites and Deszyck, 1952). The treatments were adjusted to tree size during the course of the experiment, but ranged from 0 to 13 per cent of potassium (0 to 16 per cent of K_2O) in the mixed fertilizer used throughout the experiment. During the last seven years of the experiment, the treatments ranged from 0 to 322 pounds of potassium per acre annually for Hamlins, and from 0 to 243 pounds of potassium per acre annually for Valencias. Yields were depressed by low potassium more for the Hamlin variety than for the Valencia variety during the early part of the experiment. In the last seven years of the experiment, yields of the Hamlin variety were reduced from an average of 8.61 boxes (775 pounds) per tree in the 4.2 per cent potassium-fertilizer treatment (5 per cent of K_2O) to an average of 7.12 boxes (641 pounds) per tree where potassium was omitted from the applied fertilizer mixture. Leaf potassium was reduced from a level of 1.21 to 0.72 per cent. Comparable figures for the Valencia variety were a yield reduction from 4.83 to 3.88 boxes (435 to 349 pounds) per tree, with leaf potassium values of 1.37 and 0.59 per cent, respectively.

Similar studies have been made on acid, sandy soils of the performance of Marsh grapefruit trees in relation to potassium fertilization. As with oranges, difference in fruit quality de-

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velops first in such experiments. Yield differentials were not obtained until the effects upon fruit quality had become pronounced.

In one experiment in central Florida over a period of many years (Deszyck and Koo, 1957), annual application rates to Duncan grapefruit ranging from 1.2 to 6.2 pounds of potassium per tree did not result in clear-cut differences in yield; however, the leaf analyses reported for these treatments ranged between 1.34 and 2.35 per cent of potassium. Where no potassium was applied, the potassium concentration in leaves dropped to 0.78 per cent over a seven-year period. During the last three years of the experiment, the trees receiving no potassium yielded 375 pounds of fruit per tree annually, whereas those receiving potassium ranged between 741 and 846 pounds.

In another central Florida experiment, Marsh grapefruit on rough lemon rootstock were fertilized at three levels: 0 to 50, 100, and 250 pounds of potassium per acre annually (Smith and Rasmussen, 1960, 1961*a*). These application rates over a seven-year period led to leaf potassium levels ranging from 0.71 to 2.12 per cent. Yield after the third year of treatment was reduced substantially by the low-potassium level. The usual fruit-quality differences were visible throughout the series of plots. An application of 50 pounds of potassium was made in the fall of one year, after yield had been reduced by the low-potassium level. In the following year, full yield was realized, indicating that recovery from a low-potassium level in acid, sandy soils can occur very rapidly. These authors concluded that approximately 0.75 per cent of potassium seemed to be a threshold level below which full bearing potential could not be maintained. However, fruit-quality effects were apparent well above this level.

Yields of mature Persian lime trees growing on a Lakeland fine sand were progressively increased in one out of three years with annual rates of potassium per tree of 1.2, 2.6, and 3.9 pounds. The average percentage of potassium in spring-cycle leaves sampled in the fall was, respectively, 1.14, 1.43, and 1.54 (Young and Koo, 1967).

Potassium uptake from applied fertilizers on high calcium soils is greatly restricted, compared with uptake on acid soils. This appears true whether the soil is developed under arid or humid conditions. Under most arid soil conditions where irrigation is a necessity, the amount of native available potassium in the soil frequently has been sufficient for optimum yield of citrus. This was thought generally to be the case in California until recent years. A number of experiments prior to 1940 showed no benefit of potassium fertilization (Parker and Batchelor, 1942). A leaf analysis survey (Chapman and Fullmer, 1951) indicated that few, if any, California citrus groves would give a yield response to potassium applications, but that some size increase could be expected. Since 1948, a number of experiments have demonstrated a need for potassium fertilization.

After experimental injections of potassium into tree trunks, some improvement in tree appearance was noted in Eureka lemon trees on rough lemon rootstock in Ventura County (Aldrich and Haas, 1949). Still later reports on moderately acid soils in San Diego and Ventura counties showed that annual applications equivalent to 8.3 pounds of potassium per tree did appear to increase yield (Aldrich and Coony, 1952). These relatively high potassium applications gave virtually no increase in leaf potassium levels. This is in decided contrast to results on more acid, sandy soils where leaf potassium levels would have been much higher following such applications.

In another California experiment, annual application was made of 8.3 pounds of potassium per tree to Valencia orange trees on sour orange rootstock growing in Ramona stony, fine sandy loam soil. This resulted in increased leaf potassium content three years after initial applications from 0.74 to 1.15 per cent, but gave greater yield in only one year of four reported (Embleton, Kirkpatrick *et al.*, 1956).

More recent reports (Embleton *et al.*, 1966, 1967, 1969; Embleton, Jones, and Burns, 1972; Page *et al.*, 1969) and observations by the California authors show unmistakable evidence of potassium deficiency in certain California lemon, grapefruit and orange orchards. Substantial yield increases resulted from both soil applications of potassium sulfate and spray applications of potassium nitrate. Such responses occurred where the initial percentage of potassium in five- to seven-month-old leaves from nonfruiting terminals ranged from 0.4 to 0.5.

Some of the reasons for not detecting potassium deficiences in California until recently are apparent (Embleton *et al.*, 1969). The early experiments were established without the benefit of leaf analysis; it is now evident that these numerous

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experiments were placed in orchards where potassium was already adequate.

Improved plot techniques and research technology have made it possible to conduct a more critical evaluation of potassium nutrition in the field.

In recent years, the increased use of commercial leaf analysis provided a method to detect the relatively small percentage of orchards that would likely benefit from potassium applications. The finding that leaves from fruiting terminals had a markedly lower potassium concentration than similar age leaves from nonfruiting terminals (Harding *et al.*, 1962; Embleton, Jones, and Labanauskas, 1962; Embleton *et al.*, 1963) contributed to the success of commercial use of published leaf analysis standards for the two sampling methods (Chapman, 1960; Embleton and Jones, 1963; Embleton, Jones, and Platt, 1967).

Obtaining the proper leaf age for analysis is easier with orange and grapefruit than with lemon. In the past, the general sampling practice for lemon was to select terminal leaves from the most recently matured and hardened growth. It is now evident that for lemon, which may flush at any time of the year in both coastal and intermediate areas, many past samples were of leaves that were less than five months old. Since the potassium concentration is high in young leaves and decreases with leaf age, a leaf sample of less than five months old may not indicate a deficient potassium level when based on published standards, even though a deficiency exists. Lemon leaves sampled for diagnosis of potassium status should be at least five months old or a deficiency may go undetected.

Until about 1950 manures, which are good potassium sources, were widely applied. However, the development of chemical weed control and the conversion to nontillage, the increased use of nitrogen control programs for oranges, the realization that potassium added from manure could induce or aggravate magnesium deficiency, and the change in overall economy of a manure program, have sharply reduced manure usage. Recent urban development has also caused some displacement of citrus to virgin lands, some of which are low in potassium. Thus, potassium fertilization is now an important factor for a limited citrus acreage in California.

Under humid conditions, but on fine-textured, calcareous soils, very slight differences in yield of Valencia oranges were reported over a six-year period when trees were given no potassium or 2 or 4 pounds of potassium per tree annually (Reitz and Koo, 1960). These treatments developed an extreme range in potassium content in leaves from individual plots of from 0.44 to 2.19 per cent; however, the mean percentage of potassium in leaves of the no-potassium treatments did not drop below 0.75. The size and other fruit characteristics were affected at levels higher than those bringing about reduction in yield. Potassium applications to Persian limes growing in Rockdale (oolitic limestone) soils in southern Florida increased yields in one experiment (Goldweber *et al.*, 1956) but not in another (Campbell and Orth, 1968).

Potassium fertilization was not found to increase yields in one report in South Africa (Anderssen, 1937), but yields were increased by such fertilization in a later experiment (Rosselet *et al.*, 1962). Yields were increased by potassium applications in Brazil (Dornelles, 1963; Rodriguez and Moreira, 1969). In Jamaica, Innes (1946) and Hewett (1953) reported yield increases due to potassium fertilization in some but not all experiments. In one experiment in Taiwan, substantial increases in yield of Ponkan mandarin resulted from potassium fertilization (Chu, 1964).

Boron

Yield may be appreciably limited by boron deficiency of the severity described in South Africa (Morris, 1938). Moderate deficiency is occasionally observed in Florida (Smith and Reuther, 1949; Smith, 1954). When such symptoms are observed in Florida, they are usually associated with unusually dry winters, young trees, and rootstocks other than rough lemon. Boron deficiency has developed only rarely on trees in central Florida on rough lemon rootstock.

On the basis of leaf symptoms, it is difficult to determine if a tree suffers from mild boron deficiency. Fruit symptoms are more useful but occur too late to be remedied in the current year's crop. Many leaf symptoms have been associated with boron deficiency, and many of these would be reliable in severe cases. However, in mild or marginal deficiency situations, such symptoms have been found to be unreliable or misleading and, in fact, many occur when there is no other reason to suspect boron deficiency (Willson, 1951). Leaf analysis is useful in determining boron status of trees, and leaf boron content of 50 to 100 ppm in spring-cycle leaves from nonfruiting

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twigs collected in midsummer would indicate adequate boron nutrition.

Levels higher than that range may cause boron toxicity symptoms on leaves and, if these are severe, bring about a yield reduction. Many instances of crop reduction have occurred in Florida citrus through overuse of boron.

No yield reductions were reported for three varieties of oranges on sour orange rootstock in Florida by boron treatments which led to leaf boron content as high as 392 ppm (Smith, 1955). In one grapefruit experiment, a treatment that resulted in a leaf boron content of 940 ppm reduced yield that year, but a modified treatment which resulted in only 279 ppm of boron in the succeeding year did not reduce yield compared with the check. Similar results were reported for the Thompson pink variety. These high levels in some cases resulted in slight to moderate toxicity in most grapefruit growth flushes, and sometimes slight toxicity to most orange growth flushes; but overall they had little effect on yield.

In view of the available information, both observation of fruit symptoms and leaf analysis appear to be prudent means of managing boron nutrition. Toxicity symptoms should be avoided, although their presence in mild form apparently is not apt to reduce yield or impair fruit quality.

Boron toxicity commonly has been observed in arid areas dependent on irrigation. Even a very low boron content in irrigation water is sufficient to produce boron toxicity symptoms in citrus. Irrigation waters containing over 1 ppm of boron are generally considered unsuitable for use on citrus.

Magnesium

There can be no doubt that magnesium deficiency as severe as was prevalent in the 1930's in Florida drastically curtails the productivity of citrus trees (Fudge, 1942; Camp and Sterling, 1943; and Camp, 1947). However, deficiency that severe is now virtually unknown in the world's important commercial citrus-producing areas. The degree of magnesium deficiency commonly observed consists of only a scattering of magnesium-deficient leaves on a few tree twigs.

Perhaps it is due to the relative ease with which magnesium deficiency may be recognized by its leaf symptoms that so little data exists on the relationship between level of magnesium nutrition and yield. The success of most efforts to overcome magnesium deficiency has been judged on the basis of leaf symptom elimination rather than on the basis of fruit yield. A very high degree of correlation has been found between the observable degree of magnesium deficiency of Valencia orange trees and the analysis of their leaves for magnesium (Spencer and Wander, 1960). Magnesium deficiency was not found in Valencia orange leaves when the magnesium content of a random sample of spring-cycle leaves taken in July from nonfruiting twigs were 0.33 per cent or greater. This corresponds very well with results of an earlier experiment on grapefruit, also performed in central Florida (Fudge, 1942).

In one central Florida experiment initiated on five-year-old Valencia orange trees on rough lemon rootstock, no effect on yield was observed to result from annual rates of 0.08, 0.45, or 0.90 pound of magnesium per tree. These treatments produced magnesium contents of 0.25, 0.30, and 0.36 per cent in samples of leaves collected in December. The magnesium levels probably would have been somewhat higher had the leaf samples been taken in July, as suggested above. However, at the low magnesium application rate, some visible symptoms of magnesium deficiency appeared in the leaves (Reuther and Smith, 1952*b*).

Another experiment was initiated using Valencia and Pineapple orange trees on rough lemon rootstock to evaluate several magnesium rates as well as several magnesium sources (Spencer and Wander, 1960). During the early years of the experiment, virtually no magnesium deficiency occurred in any of the treatments. However, in the first year that the trees produced a good fruit crop, extensive magnesium deficiency symptoms were observed in several of the treatments. Yields were approximately 135 pounds of fruit per tree regardless of the appearance of magnesium deficiency.

Results from experiments just discussed indicate that yields are not impaired by the presence of leaf symptoms of mild magnesium deficiency. The authors (Embleton and Jones, unpublished) have corrected mild leaf symptoms of the deficiency in several orange experiments with magnesium sprays and have detected no difference in yield over a two- or three-year period. However, in an experiment that was continued somewhat longer (Jones *et al.*, 1971) on trees with twig dieback from the deficiency, leaf symptoms were corrected during the first year with one, two or three magnesium sprays in the spring (June; May and June; April, May and June). For the next three years five- to seven-month-old spring-cycle

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leaves from these spray treatments contained more than 0.23 per cent magnesium and all leaves were free of symptoms of the deficiency. The control trees had less than 0.16 per cent magnesium and exhibited moderate deficiency symptoms. Yet, a clear increase in yield (about 120 pounds of fruit per tree) did not result until the fifth year of the experiment, and then only on trees that received two or three annual sprays. Although free of deficiency symptoms for three years, the trees' fruit yield was not increased by the single annual spray treatment. Perhaps a yield increase would have been recorded if the experiment had been continued longer. These results indicate that the recovery period from the deficiency is long, and that during this period the level of leaf magnesium associated with a yield response is higher than the level required to prevent the development of leaf symptoms. It is now clear that future experiments on magnesium nutrition should be continued longer than past experiments.

Leaf magnesium content far higher than the level at which a few leaf symptoms first appear may be attained under favorable soil conditions (Koo *et al.*, 1958). High-magnesium values may be associated with potassium deficiency; otherwise, there is no evidence that any special value is attributable to these higher levels.

Zinc, Manganese, Copper, Iron, and Molybdenum

There is little published data indicating a critical relation between nutritional levels of zinc, manganese, copper, iron, and molybdenum and the yield of citrus trees. In nearly every study made, the success of the methods used for supplying these elements has been judged on the basis of disappearance of leaf or fruit symptoms.

Reliance upon symptom expression as a criterion for adequacy of nutrition is usually justified. Where multiple deficiencies exist simultaneously or where only slight deficiency exists, questions may be raised as to the adequacy of this method for determining nutritional levels (Cohen, 1949).

A number of studies have shown that severity of leaf symptoms is closely related to leaf analysis. Zinc-deficient leaves showing almost complete yellowing were found to contain 16 ppm of zinc, yellow- and green-mottled leaves averaged 21 ppm of zinc, and light-green-mottled leaves averaged 29 ppm of zinc (Stewart *et al.*, 1955). Slight symptoms of manganese deficiency appeared on trees when general leaf samples from fruit-bearing twigs contained 35 ppm or less of manganese. Approximately 50 per cent of the trees showed manganese deficiency symptoms when general leaf samples contained approximately 20 ppm, while all trees showed leaf symptoms if general leaf samples contained 10 ppm of manganese (Connor, 1954).

When severe, symptoms are obviously correlated with yield. All reports agree that if deficiencies of any of the five elements are sufficiently great, dieback and debilitation of tree condition is brought about, and yields decline, sometimes drastically. Corrective measures applied to such trees bring about large yield increases; treatment of less severely affected trees bring about lesser yield increases. In a California study, where about 30 to 40 per cent of the leaves of trees in a Marsh grapefruit orchard were affected, a zinc spray applied in March increased the subsequent crop by about 20 per cent over untreated trees. Where trees showed only 5 to 10 per cent of mottled leaves, a spray increased the succeeding crop by approximately 11 per cent. Where almost all leaves on the trees were affected, a spray increased the yield by 552 per cent (Parker, 1937).

Prevention of mild zinc deficiency symptoms on leaves of Valencia oranges in California did not result in a yield increase, although zinc in spring-cycle leaves from nonfruiting terminals sampled annually each May was increased from 13 to 19 ppm in one experiment and from 12 to 18 ppm in another. However, correction of manganese deficiency symptoms that persisted on mature leaves resulted in an increase in yields in both experiments. In one experiment, the average increase on the average was from 6.7 to 9.6 ppm of manganese in the May-sampled leaves, and from 7 to 13 ppm in the other experiment (Labanauskas *et al.*, 1963; Labanauskas and Puffer, 1964).

Where zinc and manganese were both deficient in California coastal lemons, only the combination of soil-applied zinc and foliar-applied manganese increased yields. Foliar-applied zinc did not support a yield increase, apparently because zinc was not translocated from the sprayed spring cycle of leaves to subsequent cycles. Soil applications of zinc maintained a higher level of zinc in all growth cycles. One annual manganese spray in the spring in conjunction with soil-applied zinc did support the yield increase. In this experiment, there were no zinc deficiency symptoms on leaves of any treatments. On the manganese-sprayed treatments, manganese deficiency symptoms appeared on young leaves only, while

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in treatments without manganese the deficiency symptoms persisted on old leaves (Embleton *et al.*, 1965).

In a Florida study of young Valencia orange trees planted on rough lemon rootstock in previously uncultivated, sandy soil, applications of zinc and manganese did not have any effect on yield, although the trees occasionally showed very slight and perhaps questionable deficiency symptoms of both elements. However, copper applications gave a slight increase in numbers of fruit per tree when the trees not treated with copper showed slight copper deficiency symptoms on the fruit (Griffiths and Enzor, 1953).

In another Florida experiment, a single application of copper, zinc, and manganese sulfates broadcast in a two-year-old Valencia orange grove was effective in maintaining trees free of deficiency symptoms, and at adequate leaf analysis level for ten years (Smith, 1968).

With the possible exception of zinc in California lemons, the data cited above seem to support the commonly held belief that yield will not be limited from the nutritional standpoint if leaf and fruit symptoms of these five elements are eliminated by any of the effective treatments mentioned earlier in this chapter. In fact, in the case of manganese, a transient deficiency pattern appearing in young leaves and disappearing as they mature is not thought to be a serious yield-limiting factor in Florida (Reitz *et al.*, 1972) or in California (Embleton *et al.*, 1965; Labanauskas *et al.*, 1963; Labanauskas and Puffer, 1964).

FRUIT SIZE AND QUALITY AS INFLUENCED BY FERTILIZATION

External apperance of fruit is of primary importance for the fresh-fruit market, while quality and quantity of juice is of primary importance in fruit for processing. Numerous studies have been conducted on the effects of fertilization on citrus fruit size and quality. Many of these studies show little or no effect; others show striking differences due to various fertilizer practices.

If the level of a given element is initially high in the trees, very little or no difference may result from increasing that level. A number of the earlier experiments may have shown lack of response because of the initially high levels of the elements in question.

Studies over the years have shown that within the range of nutrient levels for maximum production only three elements—nitrogen, phosphorus, and potassium—have important influences on fruit size and quality. These three elements will be discussed in this section. (See chap. 6, pp. 186–189 for relations between leaf analysis and fruit size and quality).

Nitrogen

Generally, an increase in tree nitrogen, within the range for high-level production, will have an adverse effect on fresh-fruit quality of grapefruit and oranges, and will reduce orange fruit size. Nitrogen effects on fruit size of grapefruit have been inconsistent. Martin (1939*a*, 1939*b*) showed that high nitrogen in winter was necessary for adequate production of Arizona grapefruit, but if the high-nitrogen program continued into the summer the percentage of fancy-grade fruit was markedly reduced. High nitrogen in winter, followed by summer starvation, resulted in high production and a high percentage of fancy fruit. Jones *et al.*, (1945) showed that Arizona grapefruit on a continuing high-nitrogen program, without summer nitrogen starvation, had larger fruit that was coarser-textured, thicker in peel, and greener in color, with a lower Brix and higher acid in the juice. Hilgeman and Van Horn (1955) report lower soluble solids and higher acid in grapefruit juice with a high nitrogen program than with a low one.

A high nitrogen level in the summer in Valencia orange trees adversely affected fruit quality (Jones and Embleton, 1959). Studies of Jones, Bitters, and Finch (1944) in Arizona showed that, even though the nitrogen level in grapefruit and Valencia orange leaves was increased by winter nitrogen applications (shortly before fruit maturity), such applications did not appreciably increase the nitrogen concentrations in the juice and peel of either. Data of Khalidy and Embleton in table 5–6 show that foliar or soil-applied nitrogen in the spring increased the nitrogen concentration in leaves and young fruit but had little effect on the concentrations in the juice and peel of fruit approaching a summer harvest. It appears that to obtain maximum yield of high quality grapefruit and oranges for fresh fruit markets, readily available forms of nitrogen should be applied in winter or early spring; summer applications should be avoided.

Grapefruit studies in Florida showed that an increase in nitrogen supply resulted in smaller fruit (Smith and Rasmussen, 1961*b*; Sites *et al.*, 1961; Reitz and Hunziker, 1961). In two of these Florida experiments, leaf analysis was given. An increase in nitrogen above 2.1 per cent in a sum-

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Table 5–6
DIFFERENTIAL EFFECTS OF SOIL- AND FOLIAR-APPLIED NITROGEN ON NITROGEN CONCENTRATIONS IN YOUNG AND OLD FRUIT* AND LEAVES OF GRAPEFRUIT†

Treatments§	Concentrations of Nitrogen‡			
	November, 1967	May, 1968	June, 1968	July, 1968
		Per Cent in Dry Leaves		
No Nitrogen	2.59¶	2.49$_y$‖	2.58$_y$‖	2.28$_y$‖
Soil	2.55	2.57$_y$	2.76$_z$	2.31$_y$
Spray	2.56	2.66$_z$	2.83$_z$	2.39$_z$
Significance	NS	••	••	•••
		Per Cent in Dry Peel (from 1967 set)		
No Nitrogen	..	1.31	1.43	1.11$_y$
Soil	..	1.31	1.49	1.13$_y$
Spray	..	1.32	1.49	1.16$_z$
Significance		NS	NS	•
		Mgm Per 100 ml Juice (from 1967 set)		
No Nitrogen	..	116	115	120
Soil	..	118	113	118
Spray	..	118	112	117
Significance		NS	NS	NS
		Per Cent in Whole Small Fruit (from 1968 set)		
No Nitrogen	..	2.32$_y$	1.99$_y$	1.38$_z$
Soil	..	2.40$_y$	2.04$_y$	1.44$_y$
Spray	..	2.53$_z$	2.17$_z$	1.49$_z$
Significance		••	•••	•••

* Like the Valencia orange, summer grapefruit in the Riverside area of California are on the tree for fifteen or sixteen months; thus crops from two seasons are on the trees for a three- to four-month period.

† Previously unpublished data of Khalidy and Embleton.

‡ Means were ranked by Duncan's (1955) multiple range test as modified by Harter (1960). Means are significantly different at the 0.05 level if they do not have a subscript letter in common

§ Treatments were replicated fourteen times with single tree plots. They were: no nitrogen in 1968, 2 pounds of calcium nitrate per tree broadcasted on April 29, 1968, and urea foliar spray at 7.5 pounds per 100 gallons applied on April 29, May 22, and June 24, 1968.

¶ Pretreatment leaf sample from nonfruiting terminals of 1967 spring-cycle growth.

‖ Leaves from nonfruiting terminals of 1968 spring-cycle growth.

mer leaf sample from non-fruiting spring-cycle shoots was associated with an increase in the percentage of soluble solids and acid in the juice but had little influence on the Brix-acid ratio; in this range nitrogen had little or no effect on yield. In contrast, another Florida study, with Marsh grapefruit growing on a deep, sandy soil, where yields were progressively increased by increasing mean leaf nitrogen percentages from 2.28 to 2.51, showed that peel thickness, juice percentage, and citric acid were increased slightly and the ratio of total soluble solids to total acid was reduced slightly with a nitrogen increase (Smith, 1969*a*). More green color was reported on fruit from the high-nitrogen treatments in three of these experiments.

Jones *et al.* (1945), Innes (1946), Hilgeman and Van Horn (1955), Smith and Rasmussen (1961*b*), and Smith (1969*a*) observed an inverse relation between nitrogen level and ascorbic acid in grapefruit juice.

Numerous reports indicate a reduction in orange fruit size with an increase in the nitrogen supply (Parker and Jones, 1951; Reuther and Smith, 1952*b*; Reitz and Koo, 1960; Jones, Embleton, and Steinacker, 1957; Jones and Embleton, 1960*b*, 1961; Rosselet *et al.*, 1962; DeFossard and Lenz, 1967; Lenz, 1971; Rodriguez and Moreira, 1969). Numerous reports also show a reduction in the percentage of fancy-grade fruit with an increase in the nitrogen rate (Bouma, 1956; Jones and Embleton, 1960*b*: Oppenheimer and Heymann-Herschberg, 1954; Parker and Jones, 1951;

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Reitz and Koo, 1960). The percentage of Valencia oranges that was commercially packed was substantially reduced by a high nitrogen level in the tree (Jones and Embleton, 1960*b*).

A thicker peel, or lower percentage of juice, and coarser-textured fruit is commonly associated with a high level of nitrogen in the orange tree (Anderssen, 1950; Aso and Stein, 1967; Bouma and McIntyre, 1963; DeFossard and Lenz, 1967; Fölscher and Bruwer, 1967; Jones and Embleton, 1967; Jones, Embleton *et al.*, 1957; Lenz, 1967; Oppenheimer and Heymann-Herschberg, 1954; Reitz and Koo, 1960; Rosselet *et al.*, 1962; Rosselet *et al.*, 1963; Wallace, Cameron, and Wieland, 1955; Wallace *et al.*, 1952). DeVilliers (1969) reported that an increase in nitrogen increased peel thickness and reduced the percentage of rag but, more often than not, increased the juice content.

Green fruit color, associated with degreening and regreening, has been observed to be greater on fruits from trees at a high level of nitrogen nutrition (Jones and Embleton, 1959; Reitz and Koo, 1960; Reuther and Smith, 1952*b*; Smith, 1967*c*).

An increase in nitrogen rate reduced the concentration of ascorbic acid in orange juice (Jones and Parker, 1947; Reuther and Smith, 1952*b*; Smith, Reuther, and Scudder, 1953; Jones, Embleton, and Steinacker, 1957). Other reports show no effect of nitrogen rate on ascorbic acid in orange juice (Reuther *et al.*, 1957; Jones *et al.*, 1959; Reitz and Koo, 1960).

Observed results on the effects of varying nitrogen levels on the percentage of total soluble solids, total acid, and Brix-acid ratio in orange juice have been small and inconsistent.

Eaks and Jones (1959) showed that rind staining of navel oranges increased with increasing nitrogen.

Studies by LeRoux and Crous (1938) in South Africa indicated that more creasing of Mediterranean sweet orange occurred at a low than at a high nitrogen level. Significant creasing of Valencia oranges occurred in two out of five years in a Florida experiment, and in one of these two years the low-nitrogen treatments resulted in significantly more creasing than either the intermediate or high rates (Reitz and Koo, 1960). Although the effects of nitrogen levels on creasing of Valencia oranges were reported to be inconsistent (Jones and Embleton, 1967), most of the available data show that creasing is reduced slightly with an increase in nitrogen rate.

For fresh market the nitrogen level in the orange tree should usually be no higher than necessary to maintain production of fruit, because of the adverse effects on other factors of fruit quality.

In one experiment on Persian limes an increase in nitrogen rate increased the percentage of juice, total soluble solids and total acid in the juice (Lynch, Goldweber, and Rich, 1953; Goldweber *et al.*, 1956); in another experiment peel thickness, and percentage of juice, total soluble solids, and total acid in the juice were increased (Young and Koo, 1967).

Little data are available on the effects of nitrogen level on lemon fruit quality. Although increasing nitrogen rates increased yields and concentrations of nitrogen in leaves and fruit of California coastal lemons, effects on fruit quality factors were slight. In some years, these increasing rates increased total soluble solids or total acid in the juice and reduced ascorbic acid. Juiciness of the fruit was not affected. (Jones *et al.*, 1970).

Phosphorus

In a nine-year out-of-doors solution-culture experiment with Washington navel oranges, Chapman and Rayner (1951) showed that at either deficient or adequate phosphorus levels for yield, an increase in phosphorus level reduced fruit size. In field experiments, the phosphorus effects on orange fruit size have not been in complete accord with results from the solution-culture study. Where phosphorus increased orange yields, Allwright (1938) in one experiment, and Embleton *et al.* (1956) showed that fruit size was reduced, but Rosselet *et al.* (1962) observed an increase in fruit size and Allwright in another experiment, (1938), and Spencer (1963), Anderson (1966), Gallo (1966), and DeVilliers (1969) reported no effect on fruit size. Still other experiments showed that neither yield nor fruit size were increased with an increase in the phosphorus rate (Allwright, 1938; Crous, 1937; Smith, Reuther, and Gardner, 1949; Jones and Parker, 1949*b;* Spencer, 1963; Anderson, 1966).

With grapefruit, Innes (1946) and Bar-Akiva *et al.* (1968) showed that where yields were increased with phosphorus, fruit size was also increased. Embleton *et al.* (1967) showed no effect on lemon fruit size where yields were increased with phosphorus.

Raising the phosphorus in orange trees from a deficient to an adequate level has very marked effects on fruit quality. Varying the phos-

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phorus level in trees within the range of adequate production has less marked effects on fruit quality, but the effects are still of some consequence.

In the solution-culture study, Chapman and Raymer (1951) showed that increments of phosphorus above the range where numbers of fruit per tree were affected increased the percentage of smooth rind fruit, the juice percentage, and the total soluble solids-to-acid ratio, and reduced the concentrations of citric and ascorbic acid in juice.

In field experiments where phosphorus did not influence yields, phosphorus did not consistently affect fruit quality, but if effective at all, results were usually in accord with those from the solution-culture study (Chapman and Rayner, 1951). Morris (1937), Allwright (1938), Smith *et al.* (1963), and Jones and Parker (1949*b*) showed that an increase in the phosphorus rate increased the percentage of juice in orange fruit while Crous (1937), Smith *et al.* (1949), Spencer (1963), and Anderson (1966) observed no effect on juice percentage. Smith *et al.* (1949) showed that phosphorus reduced Valencia orange peel thickness but had no influence on the Pineapple orange; Spencer (1963) reported no effect of added phosphorus on Valencia orange while Smith *et al.* (1963) noted a reduction in peel thickness of Pineapple orange.

Morris (1937), Smith *et al.* (1949), and Anderson (1966) reported that added phosphorus reduced the concentration of total soluble solids in the juice while Crous (1937), Allwright (1938), Spencer (1963), Smith *et al.* (1963), and Jones and Parker (1949*b*) observed no effect. Crous (1937), Morris (1937), Allwright (1938), Smith *et al.* (1949), Smith *et al.* (1963), and Anderson (1966) showed that an increase in the phosphorus rate reduced the total acid concentration in orange juice, while Spencer (1963) and Jones and Parker (1949*b*) noted no effect. Smith *et al.* (1949), Smith *et al.* (1963), and Jones and Parker (1949*b*) reported that added phosphorus reduced the ascorbic acid concentration in the juice. Crous (1937), Morris (1937), Allwright (1938), Smith *et al.* (1963), and Anderson (1966) found that an increase in phosphorus increased the ratio of total soluble solids-to-acid while Smith *et al.* (1949), Spencer (1963), Jones and Parker (1949*b*), and Anderson (1966), in a second experiment, observed no effect. Smith and Reuther (1954) reported that moderate phosphorus applications frequently retarded external color development of Valencia orange and caused them to regreen readily; no similar response was observed on the Pineapple orange.

Information on the effect of phosphorus on grapefruit fruit quality in the absence of a yield increase is not available. However, where phosphorus increased yield, both peel thickness and the concentrations of total acid and ascorbic acid in the juice were reduced, total soluble solids were not affected, and juice percentage and the ratio of total soluble solids to acid were both increased (Innes, 1946; Bar-Akiva *et al.*, 1968).

Phosphorus did not affect lemon fruit quality even though it increased lemon yield (Embleton *et al.*, 1967). Phosphorus applications to Persian limes had no detectable effect on fruit quality (Goldweber *et al.*, 1956; Lynch *et al.*, 1953).

Studies by Chapman and Rayner (1951), Fourie and Joubert (1957), and LeRoux and Crous (1938) suggested that phosphorus may be involved in the orange creasing problem, but their data were not conclusive. In solution-culture studies, Haas (1950) observed more creasing associated with high than with low phosphorus. Jones and Embleton (1967) showed an increase in the incidence of creasing by increasing phosphorus from a deficient to a minimum adequate level for maintaining yield; an increase in phosphorus above the minimum adequate level had no significant influence on creasing.

Thus, when phosphorus is applied in amounts beyond those necessary to maintain orange yield, there is the possibility of a slight increase in the amount of juice in fruit and a slightly earlier fruit maturity. There is also the possibility of slightly more green rind and less ascorbic acid, total acid, and soluble solids in the juice. Consequential effects have not been observed in lemons, and data is not available for grapefruit.

Potassium

Above the deficiency range for production of numbers of fruits per tree, potassium has some important effects on fruit size and quality.

That a large increase in potassium can increase the size of fruit is substantiated by reports too numerous to cite here. Parker and Jones (1950) working with navel oranges in California, and Smith and Rasmussen (1960) working with grapefruit in Florida, came to the conclusion that an increase in potassium of up to 1.3 to 1.5 per cent in leaves from nonfruiting shoots, sampled when 4- to 9-months old, would result in an in-

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crease in fruit size. For potassium to exert its full influence on fruit size, other limiting factors, such as inadequate soil moisture, magnesium deficiency, and phosphorus deficiency, must be removed (Jones and Embleton, 1956).

Over a five-year period, Reitz and Koo (1960) varied the potassium level in leaves from nonfruiting shoots from about 0.8 to about 1.6 per cent in July leaf samples, but recorded no significance in the proportion of fancy Valencia orange fruit produced. Parker and Jones (1951) found no appreciable effect of potassium fertilization on the proportion of first and second quality Washington navel oranges. Deszyck *et al.* (1958) found that an increase in potassium level reduced the percentage of fancy Hamlin and Valencia oranges. These latter differences were associated with potassium in spring-cycle leaves from non-fruiting shoots varying from about 1 to more than 2.5 per cent in summer samples.

Field evidence indicates that an increase in potassium supply may increase peel thickness of oranges and grapefruit, thus reducing the percentage of juice in fruit (Innes, 1946; Reuther and Smith, 1952*b*; Smith and Rasmussen, 1960); frequently, however, the peel thickness and juice percentages are not affected (Deszyck *et al.*, 1958; Embleton, Jones *et al.*, 1956; Jones and Parker, 1949*b*; Reitz and Koo, 1960).

Potassium has a strong influence in increasing the percentage of total acid in juice, which usually results in a reduction in the ratio of total soluble solids to total acid in juice (Deszyck *et al.*, 1958; Embleton, Jones *et al.*, 1956; Jones and Parker, 1949*b*; Reitz and Koo, 1960; Sites, 1950; Smith and Rasmussen, 1960).

Observations on the influence of potassium on total soluble solids in the juice have been variable. Four factors probably influenced these variable results:

1. In the range of potassium that is deficient for fruit-set, an increase in potassium level appears to increase the concentration of soluble solids in the juice of fruits of equal size, but above this deficiency range an increase in the potassium level appears to have little effect on the concentration of soluble solids in the juice of equal-size fruit (Embleton *et al.*, 1969; Reuther and Smith, 1952*b*).

2. Large fruit has a lower concentration of soluble solids in the juice than small fruit (Harding and Lewis, 1941).

3. An increase in potassium generally increases fruit size.

4. Large fruit generally has a lower juice percentage than small fruit. A box of large fruit has less juice than a box of small fruit.

The net result of these factors is that above the deficiency range for fruit-set, an increase in potassium results in a reduction in the pounds of solids per box of fruit, as observed by Willson and Arey (1958).

Although the specific information is lacking, one might reason that within potassium's deficiency range an increase in potassium would not result in a reduction in the amount of solids per box of fruit, since the increase in solids concentration in the juice by potassium would offset the reduction caused by increased fruit size.

Potassium applications frequently result in an increase in ascorbic acid in the juice (Jones and Parker, 1949*b*; Smith and Rasmussen, 1960; Deszyck *et al.*, 1958; Sites, 1950; Reitz and Koo, 1960).

Reuther and Smith (1952*b*) observed that Valencia fruits from high-potassium plots did not develop satisfactory rind color and remained partially green up to harvest time. The effects of potassium on rind color were greater at a high-nitrogen level than at a low one, and the effects of potassium and nitrogen were additive. Sakamoto and Okuchi (1963) also reported that potassium applications delayed the development of orange color on satsuma orange peel.

A number of reports show a reduction in the incidence of creasing resulting from an increase in the potassium level (Chevalier, 1952; Fourie and Joubert, 1957; Jones *et al.*, 1967; Reitz and Koo, 1960; Sites and Deszyck, 1952; van Niekerk, 1955). Embleton *et al.* (1969) reported that in some experiments in which creasing was reduced with potassium applications the increase in regreening more than offset the gain by reducing creasing; in other experiments, an increase in the percentage of packout resulted from the reduction in creasing even though regreening also increased.

Fruit splitting, which was associated with drop of Hamlin fruits, was substantially reduced by increasing the percentage of potassium in leaves from 0.45 to above 1.25 (Koo, 1961). Potassium applied in alternate Februaries resulted in a lower mean potassium concentration in Valencia orange leaves and more fruit splitting than in more frequent applications (Smith, 1971).

The decision on whether or not to use potassium in an orange or grapefruit orchard, when the potassium level in trees is above that

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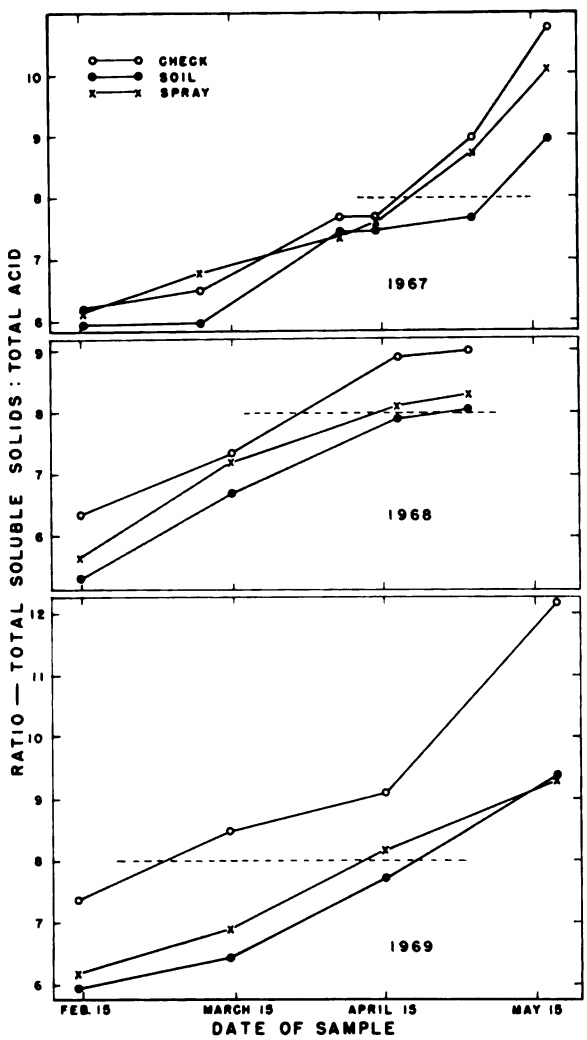

Fig. 5–6. Effect of time and potassium treatment on the ratio of total soluble solids: total acid in Valencia orange juice. Treatments: check, no potassium applied; soil, 5 pounds of potassium (as potassium sulfate) per tree broadcast in January, 1966, and again in February, 1967; spray, two sprays annually of potassium nitrate at 40 pounds per 100 gallons in the January–March period. On each sampling date two fruits of carton size 138 (average diameter 2.42 inches) were obtained from each of eight replications of single-tree plots and composited into one sample for the treatment; one fruit was obtained from the north side of the tree and one from the south. The dotted lines indicate the 8:1 ratio which is the minimum for legal maturity.

where an increase in numbers of fruit is expected, is not simple. There is a possibility of an increase in fruit size and a reduction in creasing but, along with this, one would expect to obtain coarser-textured, greener, later-maturing fruit, and fruit with a lower juice percentage. Sites (1950) estimated that the difference in reaching legal maturity for Duncan grapefruit was as much as 83 days between low- and high-potassium treatments.

The influence of potassium on delaying legal maturity of California Valencia oranges, in an orchard in which yield was increased by potassium applications, is shown in figure 5–6. During the three years, soil applications delayed legal maturity (8:1 total soluble solids:total acid ratio) from 19 to 52 days, while spray applications of potassium nitrate delayed maturity from 1 to 42 days. The differences in the ratios from year to year are probably due to weather factors (available heat units during the April–May period of the year the fruit in question were set) (Jones, Embleton, and Cree, 1962). The data in figure 5–6 suggest that in years of early maturity on low-potassium trees, increasing potassium delays fruit maturity more than in years of late maturity. Also, the variation among years in time of reaching legal maturity in trees supplied with potassium is much less than in trees low in potassium.

Although increasing rates of applied potassium increased yields of Persian limes in Florida, fruit quality was not affected in one experiment (Young and Koo, 1968); in another, however, added potassium appeared to increase the percentage of juice and total acid in the juice as well as the weight of individual fruits (Goldweber *et al.*, 1956; Lynch *et al.*, 1953).

In California, potassium applications to lemons reduced peel thickness and increased juice percentage, total juice acid, pounds of total acid per ton of fruit, and concentration of ascorbic acid in the juice. The lower the initial potassium level in leaves, and the greater the potassium increase in leaves, the greater were the effects on fruit quality and yield. However, the effects on quality were measurable when potassium was initially high, and no yield increase was observed. Where potassium limited yields, applications resulted in more elongated fruit and a delay in development of yellow coloring on the fruit. This latter effect permitted fruits to remain on the tree longer so they were larger at harvest time. These effects on fruit quality are similar to those reported for oranges and grapefruit. However, they differ in that potassium applications to lemon trees reduced peel thickness and increased the percentage of juice in the fruit. All of the above-mentioned effects are beneficial for lemons (Embleton *et al.*, 1964; Embleton and Jones, 1966*a*,

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1966*b*). Observations similar to these were made in Sicily by Crescimanno (1957).

SOME IMPORTANT INTERRELATIONS AMONG FERTILIZER ELEMENTS

The planning of a fertilizer program would be much simplified if one could apply one mineral element to a tree and influence the level in the tree of that element only. Unfortunately, such simplicity rarely, if ever, exists. Some of the nutritional interrelations among elements are of practical concern. In general, the antagonistic or synergistic effect of one element on another is of greater magnitude in sandy soils than in clay soils. Also, the antagonistic or synergistic effect of one added element on another is likely to be greater in soils in which the concentrations in the soil of the elements in question are initially low, than when they are initially high.

An increase or decrease in the nitrogen rate may have important effects on the nutrition of a number of elements in the plant. In one experiment on a sandy loam soil that was phosphorus deficient, high nitrogen rates aggravated the phosphorus deficiency of Valencia oranges. Omission of nitrogen fertilization for several years resulted in a reduction in the nitrogen concentration, an increase in the phosphorus concentration in leaves, and an improvement in tree condition, yield, and fruit quality when compared with trees that continued to receive high nitrogen rates. However, the general improvement achieved by omitting nitrogen was not as great as that which occurred when phosphorus was applied (Embleton *et al.*, 1952; Embleton and Jones, unpublished). Heymann-Herschberg (1952*b*) warned that, under conditions of low nitrogen supply, phosphorus applications may reduce yields of the Shamouti orange in Israel. Rosselet *et al.* (1962) observed that ammonium sulfate applications reduced yields of Valencia oranges in the absence of superphosphate applications, but increased yields when superphosphate was applied. This relation would not have been observed had not phosphorus been limiting.

An increase in nitrogen level usually results in an increase in the magnesium level in citrus trees. Reitz and Koo (1960) observed magnesium deficiency symptoms on Valencia orange trees in Florida which received a low rate of nitrogen, and no magnesium deficiency symptoms on trees that received an intermediate or high rate of nitrogen. The symptoms were well correlated with the concentration of leaf magnesium. Similar observations have been made by others (Byers and Joubert, 1952; Haas, 1948).

The concentrations of sulfur and boron in leaves may be reduced by an increase in the nitrogen rate (Chapman and Liebig, 1940; Eaton, 1935; Foote and McElhiney, 1937; Haas and Thomas, 1928; Jones *et al.* 1963). Jones *et al.* (1963) reported that higher nitrogen rates should be used in California orange orchards where the sulfate or boron or both concentrations in leaves are high because of use of irrigation water containing high amounts of these two constituents. Under such conditions, a nitrogen program to give the fruit quality desired may result in an increase in accumulation of sulfate or boron or both in the leaves. Such an accumulation results in premature defoliation and possible loss in yield. An increase in the nitrogen rate reduces the accumulation of these elements in leaves and results in better tree condition, but has an adverse effect on fruit quality. A leaf analysis for nitrogen, sulfate, and boron can prove very beneficial in diagnosing this type of problem (see chap. 6).

In Florida, differential nitrogen rates did not influence the sulfur concentration in orange leaves (Rasmussen and Smith, 1958). Sulfur excess was not a problem in the Florida study.

An increase in the nitrogen rate applied to orange trees has been observed to aggravate zinc deficiency (Camp and Fudge, 1945; Reuther and Smith, 1950).

Evidence is accumulating rather rapidly showing the importance of phosphorus fertilization on copper and zinc nutrition. Many studies in solution, sand, and soil cultures have shown a reduction in the concentrations of copper and zinc in the leaves, resulting from an increase in phosphorus supply. Under some conditions, this reduction may be enough to induce copper deficiency (Bingham and Martin, 1956; Bingham, Martin, and Chastain, 1958). An increase in the amount of phosphorus applied to orange trees growing on a Davie mucky fine sand in Florida aggravated copper deficiency (Young and Forsee, 1949). In pot studies, Spencer (1966) observed that copper toxicity symptoms of Cleopatra mandarin seedlings, growing in Lakeland fine sand, were reduced and plant growth increased by phosphorus additions. It was observed in the field in California that large applications of manure and phosphorus to a sandy loam soil induced severe copper and zinc deficiencies, and these deficiencies were corrected with sprays of copper and zinc. Numerous reports show that an increase

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in the phosphorus rate may induce or accentuate zinc deficiency (Bathhurst, 1945; Byers and Joubert, 1952; Reuther and Crawford, 1946; West, 1938).

One common observation is the depressive effect of potassium applications on leaf magnesium concentrations. In some cases, the depression is enough to bring on or aggravate magnesium deficiency (Bingham, McColloch, and Aldrich, 1956; Reitz and Koo, 1960). The potassium in organic materials such as manure may be enough to appreciably reduce the magnesium concentration in leaves after a few years of application. Induction or accentuation of magnesium deficiency has been observed several times following continued use of steer manure.

The effect of copper accumulations in the surface soil on the increased incidence of iron deficiency has been previously discussed in this chapter. Whether this is a direct effect of copper on the nutrition of iron in the plant or an indirect effect caused by the development of stubby roots in the surface soil is debatable. Regardless of the mechanism of the development of iron chlorosis under these conditions, the root growth and iron deficiency condition can be improved by inactivating the copper in the surface soil by liming (Ford, 1953; Reuther and Smith, 1952*a*, 1953; Reuther *et al.*, 1953; Smith and Specht, 1952).

Although arsenic is not an essential element, it is sprayed on trees in some areas to hasten fruit maturity. Such sprays have been observed on occasion to accentuate the symptoms of boron deficiency (Roy, 1943; Smith and Reuther, 1949). Symptoms of arsenic toxicity are more pronounced at low- than at high-nitrogen levels (Smith and Rasmussen, 1961*b*).

Leaf analysis and fertilizer studies and solution-, sand-, and soil-culture studies have shown many other interrelations among elements. However, in this section, we have only selected some examples of interrelations which can result in conditions in the orchard that suggest the need for corrective measures. Undoubtedly, some important interrelations have been overlooked, and with more research and experience, additional interrelations of importance to the citrus grower will be found.

LITERATURE CITED

ALDRICH, D. G., JR. 1949. The effect of soil acidification on some physical and chemical properties of three irrigated soils. Soil Sci. Soc. Amer. Proc. **13**:191–96.

ALDRICH, D. G. JR., and J. R. BUCHANAN. 1954. Soil phosphorus supply in healthy and phosphorus-deficient citrus orchards in southern California. Proc. Amer. Soc. Hort. Sci. **63**:32–36.

ALDRICH, D. G., JR., and J. J. COONY. 1952. A field response of citrus to phosphorus and potassium fertilization. Proc. Amer. Soc. Hort. Sci. **59**:13–21.

ALDRICH, D. G. JR., and A. R. C. HASS. 1949. Response of lemon trees to phosphorus and potassium. Calif. Citrog. **35**:5, 22–24.

ALDRICH, D. G. JR., and O. C. TAYLOR. 1954. Nitrogen fertilizer practices in California citrus orchards. Calif. Citrog. **39**:144, 162–64, 166–68.

ALDRICH, D. G., JR., E. R. PARKER, and H. D. CHAPMAN. 1945. Effects of several nitrogenous fertilizers and soil amendments on the physical and chemical properties of an irrigated soil. Soil Sci. **59**:299–312.

ALDRICH, D. G., JR., A. P. VANSELOW, and G. R. BRADFORD. 1951. Lithium toxicity in citrus. Soil Sci. **71**:291–95.

ALLWRIGHT, W. J. 1938. Final report on the fertilizer trials at Rustenburg, Western Transvaal. Citrus Grow. [So. Africa] **52**:5–19.

ANDERSON, C. A. 1966. Effects of phosphate fertilizer on yield and quality of 'Valencia' oranges. Proc. Fla. State Hort. Soc. **79**:36–40.

——— 1968. Effects of gypsum as a source of calcium and sulfur on tree growth, yields, and quality of citrus. Proc. Fla. State Hort. Soc. **81**:19–24.

——— 1971. Dolomitic limestone as a source of magnesium for citrus. Proc. Soil and Crop Sci. Soc. Fla. **30**:150–57.

——— 1972. Effects of soil pH and calcium on yields and fruit quality of young Valencia oranges. Proc. Fla. State Hort. Soc. **84**:4–10.

ANDERSON, C. A., and D. V. CALVERT. 1967. Effects of phosphate fertilizer on young citrus trees on flatwood soils. Proc. Fla. State Hort. Soc. **80**:19–25.

ANDERSSEN, F. G. 1937. Citrus manuring—its effect on cropping and on the composition and keeping quality of oranges. Jour. Pomol. **15**:117–59.

——— 1950. Horticultural problems in the Union. Farming So. Africa **25**:467–70.

ARMSTRONG, W. W. JR., and J. R. FURR. 1956. Experiment control of lime-induced iron chlorosis in trifoliate orange seedlings by soil applications of some iron compounds. Proc. Rio Grande Val. Hort. Soc. **10**:43–48.

ARNOT, R. H. 1946. Potassium deficiency in citrus. Jour. Austral. Inst. Agr. Sci. **12**:110–13.

ASO, P. J., and E. STEIN. 1967. Epoca y dosis de fertilización nitrogenada en naranjos Valencia. Rev. Ind. Agr. Tucumán **45**:107–19.

BAHRT, G. M., and W. R. ROY. 1940. Progress report of the effects of no potassium and various sources and amounts of potassium on citrus. Proc. Fla. State Hort. Soc. **53**:26–34.

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BAR-AKIVA, A., V. HILLER, and J. PATT. 1968. Effect of phosphorus and chicken manure on yield, fruit quality and leaf composition of grapefruit trees. Proc. Amer. Soc. Hort. Sci. **93**:145–52.

BAR-AKIVA, A., A. SHAKED, and J. SAGIV. 1967. The use of nitrate reductase activity for the appraisal of nitrogen status and productivity of grapefruit orchard trees. HortScience **2**:51–53.

BAR-AKIVA, A., D. TAL, and J. HIRSH. 1969. Use of aerial sprays for correcting magnesium deficiency in orange groves. Exp. Agr. **5**:339–42.

BATHHURST, A. C. 1945. The effects of superphosphate on orange trees. Farming So. Africa **20**:351–53.

BESTER, D. H. 1969. Fertilizer interactions of navel oranges in South Africa as revealed by leaf analysis. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. **3**:1641–60. Univ. of Calif. Riverside, Calif.

BEUTEL, J. A., E. SHEPHARD, J. W. HUFFMAN, C. SALVERSON, J. J. STARK, G. WINRIGHT, and C. PERRY. 1958. Manure—value and uses for crops. Los Angeles County Agr. Ext. Serv., Los Angeles, California. [Mimeo.] 14 pp.

BINGHAM, F. T. 1959. Micronutrient content of phosphorus fertilizers. Soil Sci. **88**:7–10.

BINGHAM, F. T., S. DAVIS, and E. SHADE. 1971. Water relations, salt balance, and nitrate leaching losses of a 960-acre citrus watershed. Soil Sci. **112**:410–18.

BINGHAM, F. T., and M. J. GARBER. 1960. Solubility and availability of micronutrients in relation to phosphorus fertilization. Soil Sci. Soc. Amer. Proc. **24**: 209–13.

BINGHAM, F. T., and J. P. MARTIN. 1956. Effects of soil phosphorus on growth and minor element nutrition of citrus. Soil Sci. Soc. Amer. Proc. **20**:382–85.

BINGHAM, F. T., J. P. MARTIN, and J. A. CHASTAIN. 1958. Effects of phosphorus fertilization of California soils on minor element nutrition of citrus. Soil Sci. **86**:24–31.

BINGHAM, F. T., R. C. MCCOLLOCH, and D. G. ALDRICH. 1956. Interrelation of soil potassium and magnesium. Citrus Leaves **36**(1):6–7, 20.

BINGHAM, F. T., A. L. PAGE, and G. R. BRADFORD. 1964. Tolerance of plants to lithium. Soil Sci. **98**:4–8.

BITCOVER, E. H., and I. W. WANDER. 1950. Some observations on nitrite formation and the absorption of nitrogen by citrus. Plant Physiol. **25**:461–68.

BLISS, D. E. 1944. Air and soil temperatures in a California citrus orchard. Soil Sci. **58**:259–74.

BOUMA, D. 1956. Studies in citrus nutrition. II. Phosphorus deficiency and fruit quality. Austral. Jour. Agr. Res. **7**:261–71.

——— 1959. Growth, yield, and fruit quality in a factorial field experiment with citrus in relation to changes in phosphorus nutrition. Austral. Jour. Agr. Res. **10**:41–51.

——— 1960. The effect of ammonium sulfate usage on the availability of soil phosphorus to citrus. Austral. Jour. Agr. Res. **11**:292–303.

BOUMA, D., and G. A. MCINTYRE. 1963. A factorial field experiment with citrus. Jour. Hort. Sci. **38**:175–98.

BOWMAN, F. T. 1956. Citrus-growing in Australia. Angus and Robertson, Sydney. 311 pp.

BRADFORD, G. R. 1961. Lithium toxicity in southern California citrus. Calif. Agr. **15**(12):14.

——— 1963. Lithium in California's water resources. Calif. Agr. **17**(5):6–8.

BROADBENT, F. E., and F. CLARK. 1965. Denitrification. *In:* Bartholomew, W. V., and F. E. Clark (eds.). Soil nitrogen. pp. 344–59. Amer. Soc. Agron., Inc. Madison, Wis.

BROADBENT, F. E., and T. NAKASHIMA. 1967. Reversion of fertilizer nitrogen in soils. Soil Sci. Soc. Amer. Proc. **31**:648–52.

BROADBENT, F. E., K. B. TYLER, and G. N. HILL. 1957. Nitrification of ammoniacal fertilizers in some California soils. Hilgardia **27**:247–67.

BROADBENT, F. E., G. N. HILL, and K. B. TYLER. 1958. Transformations and movement of urea in soils. Soil Sci. Soc. Amer. Proc. **22**:303–07.

BROWNELL, P. F. 1965. Sodium as an essential micronutrient element for a higher plant (*Atriplex vesicaria*). Plant Physiol. **40**:460–68.

BROWNELL, P. F., and J. G. WOOD. 1957. Sodium as an essential micronutrient element for *Atriplex vesicaria*, Heward. Nature **179**:635–36.

BRYAN, O. C. 1933. The accumulation and availability of phosphorus in old citrus grove soils. Soil Sci. **36**: 245–59.

BUCKMAN, H. O., and N. C. BRADY. 1969. The nature and properties of soils. Seventh ed. The MacMillan Co., New York. 653 pp.

BURGESS, P. S., and G. G. POHLMAN. 1928. Citrus chlorosis as affected by irrigation and fertilizer treatments. Univ. Ariz. Agr. Expt. Sta. Bul. **124**:183–232.

BYERS, E., and G. F. JOUBERT. 1952. Mineral deficiencies in citrus in the Citrusdal area. Farming So. Africa **27**:508–10.

CAHOON, G. A., P. B. LOMBARD, B. L. GROVER, and W. W. JONES. 1963. Water-penetration profiles in a furrow-irrigated Washington navel orange orchard as affected by nitrogen sources and cultural treatments. Soil Sci. **95**:400–06.

CAHOON, G. A., E. S. MORTON, W. W. JONES, and M. J. GARBER. 1959. Effects of various types of nitrogen fertilizers on root density and distribution as related to water infiltration and fruit yields of Washington navel oranges in a long-term fertilizer experiment. Proc. Amer. Soc. Hort. Sci. **74**:289–99.

CALVERT, D. V. 1969. Spray applications of potassium nitrate for citrus on calcareous soils *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. **3**: 1587–97. Univ. of Calif. Riverside, Calif.

——— 1970. Response of 'Temple' oranges to varying rates of nitrogen, potassium, and magnesium. Proc. Fla. State Hort. Soc. **83**:10–15.

CALVERT, D. V., and H. J. REITZ. 1964. Effects of rate and frequency of fertilizer applications on yield and quality of Valencia oranges in the Indian River area. Proc. Fla. State Hort. Soc. **77**:36–41.

——— 1966. Response of citrus growing on calcareous soil to soil and foliar applications of magnesium. Proc. Fla State Hort. Soc. **79**:1–6.

CAMP, A. F. 1934. Zinc sulfate as a soil amendment in citrus groves. Proc. Fla. State Hort. Soc. **47**:33–39.

——— 1945. Zinc as a nutrient in plant growth. Soil Sci. **60**:157–64.

——— 1947. Magnesium in citrus fertilization in Florida. Soil Sci. **63**:43–52.

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CAMP, A. F., and H. O. STERLING. 1943. Production studies. Univ. Fla. Agr. Expt. Sta. Ann. Rept. **1943**:202–03.

CAMPBELL, C. W., and P. G. ORTH. 1968. Effects of three years of differential nitrogen and potassium application on 'Tahiti' lime yield and leaf analysis on Rockdale soil in Florida. Proc. Fla. State Hort. Soc. **81**:336–40.

CARTER, J. N., and F. E. ALLISON. 1961. The effect of rates of application of ammonium sulfate on gaseous losses of nitrogen from soils. Soil Sci. Soc. Amer. Proc. **25**:484–86.

CHAPMAN, H. D. 1934. The phosphate of southern California soils in relation to citrus fertilization. Univ. Calif. Agr. Expt. Sta. Bul. **571**: 22 pp.

——— 1944. The distribution of nitrogen materials in irrigation water. Proc. 19th Ann. Meeting Natl. Joint Comm. Fert. Appl. **19**:18–23.

——— 1951. Reasons for the high nitrogen requirement of citrus in California. Calif. Citrog. **36**:223, 250–53.

——— 1960. Leaf and soil analysis in citrus orchards. Univ. Calif. Div. Agr. Sci. Ext. Serv. Manual **25**: 53 pp.

——— 1964. Potash in relation to California citrus. Calif. Citrog. **49**:454–55, 464, 466, 468.

——— 1968. The mineral nutrition of citrus. *In:* Reuther, W., L. D. Batchelor, and H. J. Webber (eds.). The citrus industry, Rev. ed. **2**:127–289. Univ. Calif. Div. Agr. Sci., Berkeley, Calif.

CHAPMAN, H. D., and S. M. BROWN. 1941. The effects of sulfur deficiency on citrus. Hilgardia **14**:185–201.

CHAPMAN, H. D., and F. FULLMER. 1951. Potassium and phosphorus. Status of California citrus orchards as indicated by leaf analysis surveys. Citrus Leaves **31**(2):10, 11, 36–39.

CHAPMAN, H. D., HARRIETANN JOSEPH, and D. S. RAYNER. 1969. Nitrogen nutrition in young lemons. Calif. Citrog. **54**:192–96, 198–200.

CHAPMAN, H. D., and G. F. LIEBIG, JR. 1940 Nitrate concentration and ion balance in relation to citrus nutrition. Hilgardia **13**:141–73.

CHAPMAN, H. D. and E. R. PARKER. 1942. Weekly absorption of nitrate by young, bearing orange trees growing out of doors in solution cultures. Plant Physiol. **17**:366–76.

CHEN, W. C. 1954. Studies on the absorption of nitrogen by citrus from foliar applications of urea. Mem. Coll. Agr. Nat. Taiwan Univ. **3**(3):43–62.

CHEVALIER, G. 1952. La boursouflure des agrumes. Fruits Primeurs Afrique du Nord **22**:339–43.

CHIN, W., and W. KROONTJE. 1962. Mechanisms of urea adsorption by soils. Soil Sci. Soc. Amer. Proc. **26**: 479–81.

——— 1963. Urea hydrolysis and subsequent loss of ammonia. Soil Sci. Soc. Amer. Proc. **27**:316–18.

CHU, C. C. 1964. Effects of potassium on fruit size, quality, and yield of Ponkan (*Citrus poonensis*). Potash Review Subj. **24**(23):1–3.

COHEN, A. 1949. The manganese content of Shamouti orange leaves. Palestine Jour. Bot. [Rehovot] **7**: 85–93.

CONNOR, J. 1954. Effect of cultural practices on the manganese status of soil and citrus trees under irrigation. Austral. Jour. Agr. Res. **5**:31–38.

COOPER, W. C. 1961. Toxicity and accumulation of salts in citrus trees on various rootstocks in Texas. Proc. Fla. State Hort. Soc. **74**:95–104.

COOPER, W. C., and A. PEYNADO. 1954. Correction of iron chlorosis of young grapefruit trees on Cleopatra mandarin rootstock with chelated iron. Proc. Rio Grande Val. Hort. Inst. **8**:106–09.

——— 1959. Experimental control in citrus trees of iron chlorosis associated with the virus disease cachexia and high soil salinity by applications of iron chelate. Jour. Rio Grande Val. Hort. Soc. **13**:75–80.

CRESCIMANNO, F. G. 1957. La nutrizione minerale degli agrumi con particolare riguardo al potassio (Richerche sperimentali sul limone). G. Mori & Figli, Palermo. 40 pp.

CROUS, P. A. 1937. Superphosphate experiment, White River, 1937. Citrus Grow. [So. Africa.] **51**:15–17.

CUTULI, G. 1968. Field and laboratory experiments with citrus plants on the uptake of potash by the foliar route. Potash Rev. Subject 8, Suite **19**:1–10.

DEFOSSARD, R. A., and F. H. LENZ. 1967. Influence of nitrogen fertilization on quality, respiration and storage life of Washington navel oranges. Qual. Plant. Mater. Veg. **14**:289–304.

DEKOCK, P. C. 1956. Heavy metal toxicity and iron chlorosis. Ann. Bot. (n.s.) **20**:133–41.

DEKOCK, P. C., and R. L. MITCHELL. 1957. Uptake of chelated metals by plants. Soil Sci. **84**:55–62.

DEMETRIADES, S. D., N. A. GAVALAS, and S. E. PAPADOPOULAS. 1964. Trials for the control of lime-induced chlorosis in fruit trees in Greece. I. Preliminary observations on peach and lemon trees. Ann. Inst. Phytopath. [Benaki] **7**:28–36.

DESZYCK, E. J., and R. C. J. KOO. 1957. Potash fertilization in a mature Duncan grapefruit orchard. Proc. Soil Crop Sci. Soc. Fla. **17**:302–10.

DESZYCK, E. J., R. C. J. KOO, and S. V. TING. 1958. Effect of potash on yield and quality of Hamlin and Valencia oranges. Proc. Soil Crop Sci. Soc. Fla. **18**: 129–35.

DEVILLIERS, J. I. 1942. Trace element deficiencies in citrus. Results obtained in eastern Transvaal. Farming So. Africa **17**:337–40.

——— 1969. The effect of differential fertilization on the yield, fruit quality, and leaf composition of oranges. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. **3**:1661–68. Univ. of Calif. Riverside, Calif.

DORNELLES, C. M. 1963. Initial results of an experiment on the manuring of orange trees. Fertilite No. **19**: 25–30.

DUNCAN, D. B. 1955. Multiple range and multiple F tests. Biometrics **11**:1–42.

EAKS, I. L., and W. W. JONES. 1959. Rind staining and breakdown of navels. Calif. Citrog. **44**:390, 400, 402.

EATON, F. M. 1935. Boron in soils and irrigation waters and its effect on plants with particular reference to the San Joaquin Valley of California. U. S. Dept. Agr. Tech. Bul. **448**:132 pp.

EL-MAHMOUDI, L. 1959. Effect of three nitrogen levels on growth and fruiting of young trees in sandy soils. Agr. Res. Rev. 37:68–78.

EMBLETON, T. W., and W. W. JONES. Unpublished data on file at Dept. of Plant Sciences, Univ. Calif. Citrus Res. Center, Riverside.

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Original from PENN STATE

——— 1955. Under tillage and nontillage. Manure as a source of nitrogen. Calif. Citrog. **41**:79–80.

——— 1959*a*. Correction of magnesium deficiency of orange trees in California. Proc. Amer. Soc. Hort. Sci. **74**:280–88.

——— 1959*b*. Magnesium deficiency of orange trees and its correction by magnesium nitrate foliage sprays. Sunkist Pest Control Circ. **265**:2 pp.

——— 1963. Leaf analysis—fertilizer program for oranges. Calif. Citrog. **48**:339, 348, 350–51.

——— 1966*a*. Potassium and lemon fruit quality. Calif. Citrog. **51**:269.

——— 1966*b*. Effects of potassium on peel thickness and juiciness of lemon fruits. HortScience **1**:25–26.

EMBLETON, T. W., W. W. JONES, C. B. CREE, and M. J. GARBER. 1959. Effects of N on Valencia production. Calif. Citrog. **45**:22–24.

EMBLETON, T. W., W. W. JONES, and J. D. KIRKPATRICK. 1956. Influence of applications of dolomite, potash, and phosphate on quality, grade, and composition of Valencia orange fruit. Proc. Amer. Soc. Hort. Sci. **67**:191–201.

EMBLETON, T. W., W. W. JONES, and C. K. LABANAUSKAS. 1962. Sampling orange leaves—leaf position important. Calif. Citrog. **47**:382, 396.

EMBLETON, T. W., W. W. JONES, C. K. LABANAUSKAS, and R. G. PLATT. 1971. Leaf analysis and phosphorus fertilization of oranges. Citrograph **56**:101 124.

EMBLETON, T. W., W. W. JONES, and A. L. PAGE. 1964. Potash hunger in lemons. Better Crops with Plant Food **48**(4): cover, 2–5.

——— 1966. Potassium deficiency in Valencia oranges in California. HortScience **1**:92.

——— 1967. Potassium and phosphorus effects on deficient 'Eureka' lemon trees and some salinity problems. Proc. Amer. Soc. Hort. Sci. **91**:120–27.

EMBLETON, T. W., W. W. JONES, A. L. PAGE, and R. G. PLATT. 1969. Potassium and California citrus. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. **3**:1599–1603, Univ. of Calif. Riverside, Calif.

EMBLETON, T. W., W. W. JONES, and R. G. PLATT. 1967. California oranges. Leaf analysis and potassium fertilization. Calif. Citrog. **52**:399–400.

——— 1969. Pointers on winter fertilization of citrus. Citrograph. **55**:17–18, 28.

EMBLETON, T. W., J. D. KIRKPATRICK, W. W. JONES, and C. B. CREE. 1956. Influence of applications of dolomite, potash, and phosphate on yield and size of fruit and on composition of leaves of Valencia orange trees. Proc. Amer. Soc. Hort. Sci. **67**:183–90.

EMBLETON, T. W., J. D. KIRKPATRICK, and E. R. PARKER. 1952. Visible response of phosphorus-deficient orange trees to phosphatic fertilizers, and seasonal changes in mineral constituents of leaves. Proc. Amer. Soc. Hort. Sci. **60**:55–64.

EMBLETON, T. W., C. K. LABANAUSKAS, W. W. JONES, and C. B. CREE. 1963. Interrelations of leaf sampling methods and nutritional status of orange trees and their influence on the macro- and micronutrient concentrations in orange leaves. Proc. Amer. Soc. Hort. Sci. 82:131–41.

EMBLETON, T. W., E. F. WALLIHAN, and G. E. GOODALL. 1965. Effectiveness of soil vs. foliar applied zinc, and of foliar applied manganese on California lemons. Proc. Amer. Soc. Hort. Sci. **86**:253–59.

EMBLETON, T. W., E. F. WALLIHAN, C. K. LABANAUSKAS, and G. E. GOODALL. 1964. Soil applications of zinc for citrus. Calif. Citrog. **49**:491–96.

ERNST, J. W., and H. F. MASSEY. 1960. The effects of several factors on volatilization of ammonia formed from urea in the soil. Soil Sci. Soc. Amer. Proc. **24**:87–90.

FELIZARDO, B. C., N. L. GALVEZ, and P. S. DAVIDE. 1961. Response of citrus to fertilization. Philipp. Agr. **45**:95–102.

FLETCHER, W. A. 1959. Citrus orchard nutrition and soil management. New Zealand Jour. Agr. **98**:565, 567, 569, 571–72.

FLOYD, B. F. 1908. Leaf spotting of citrus. Univ. Fla. Agr. Expt. Sta. Ann. Rept. **1908**:91–93.

——— 1914. Bordeaux mixture for the control of dieback. Univ. Fla. Agr. Expt. Sta. Ann. Rept. **1913**: 27–30.

FÖLSCHER, W. S. and A. A. B. BRUWER. 1967. Nutrient element status of leaves and quality characteristics of Valencia oranges. So. African Jour. Agr. Sci. **10**: 267–77.

FOOTE, F. J., and J. B. MCELHINEY. 1937. Effect of available nitrogen in soil on sulfate and boron in lemon leaves. Calif. Citrog. **22**:346, 378–80.

FORD, H. W. 1953. Root distribution of chlorotic and iron-chelate-treated trees. Proc. Fla. State Hort. Soc. **66**:22–26.

——— 1957. Root distribution of citrus trees. Univ. Fla. Agr. Expt. Sta. Ann. Rept. **1957**:207.

FORD, H. W., W. REUTHER, and P. F. SMITH. 1957. Effect of nitrogen on root development of Valencia orange trees. Proc. Amer. Soc. Hort. Sci. **70**:237–44.

FOURIE, S., and G. F. JOUBERT. 1957. The effect of potash and phosphate on the yield and "creasing" of navel oranges in the Citrusdal area. Citrus Grow. [So. Africa] **277**:1, 3.

FREDERICK, L. R. 1956. The formation of nitrate from ammonium nitrogen in soils: I. Effect of temperature. Soil Sci. Soc. Amer. Proc. **20**:496–500.

FUDGE, B. R. 1942. Early diagnosis of magnesium deficiency in citrus. Proc. Fla. State Hort. Soc. **55**:17–21.

GOLDWEBER, S., M. BOSS, and S. J. LYNCH. 1956. Some effects of nitrogen, phosphorus and potassium fertilization on the growth, yield and fruit quality of Persian limes. Proc. Fla. State Hort. Soc. **69**:328–32.

GRIFFITHS, J. T., and J. K. ENZOR, JR. 1953. A preliminary report on the requirements of young Valencia trees for zinc, manganese, and copper when fertilized at two different rates. Proc. Fla. State Hort. Soc. **66**:27–33.

GROSSENBACHER, J. G. 1916. Some bark diseases of citrus trees in Florida. Phytopathology **6**:29–50.

HAAS, A. R. C. 1948. Magnesium deficiency and its effect on citrus. Calif. Citrog. **33**:134, 146–48, 150.

——— 1950. The relation of phosphorus to creasing and puffing in Valencia oranges. Calif. Citrog. **35**:277–78, 298–300.

HAAS, A. R. C., and E. E. THOMAS. 1928. Effect of sulfate on lemon leaves. Bot. Gaz. **86**:345–54.

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HARDING, P. L., and W. E. LEWIS. 1941. The relation of size of fruit to solids, acid and volume of juice in the principal varieties of Florida oranges. Proc. Fla. State Hort. Soc. **54**:52–56.

HARDING, R. B. 1953. Soil phosphorus in California orange orchards in relation to yield, fruit size, and phosphorus in leaves. Proc. Amer. Soc. Hort. Sci. **61**:31–37.

——— 1954. Surface accumulations of nitrates and other soluble salts in California orange orchards. Soil Sci. Soc. Amer. Proc. 18:369–72.

HARDING, R. B., T. W. EMBLETON, and W. W. JONES. 1963. Leaching and gaseous losses of nitrogen from some nontilled California soils. Calif. Citrog. **48**:317–24.

HARDING, R. B., M. P. MILLER, and M. FIREMAN. 1958. Absorption of salts by citrus leaves during sprinkling with water suitable for surface irrigation. Proc. Amer. Soc. Hort. Sci. **71**:248–56.

HARDING, R. B., P. F. PRATT, and W. W. JONES. 1958. Changes in salinity, nitrogen, and soil reaction in a differentially fertilized irrigated soil. Sci. **85**:177–84.

HARDING, R. B., and T. M. RYAN. 1961. Soil salinity and water distribution under nontillage and tillage in a differentially fertilized, irrigated citrus orchard. Proc. Amer. Soc. Hort. Sci. **77**:155–66.

HARDING, R. B., T. M. RYAN, and G. R. BRADFORD. 1962. A comparison of the macroelement composition of orange leaves from nonfruiting and fruiting terminals. Proc. Amer. Soc. Hort. Sci. **80**:255–58.

HARTER, L. H. 1960. Critical values for Duncan's new multiple range test. Biometrics. **16**:671–85.

HEWETT, C. W. 1953. Citrus check fertilizer trials. Dept. Agr. Jamaica Inv. Bul. (n.s.) **53**:123–30.

HEYMANN-HERSCHBERG, LOTTE. 1951. Magnesium deficiency of Shamouti orange trees and its treatment. Palestine Jour. Bot. [Rehovot] 8(1):76–83.

——— 1952*a*. Soil and leaf analyses as indicators of fertiliser requirement in Shamouti orange groves. Bul. Res. Coun. Israel 1(4):20–37.

——— 1952*b*. Phosphorus fertilization of Shamouti orange groves. Ktavim [Israel] **2–3**:19–22, 83–92.

——— 1956. A survey of the effect of fertilizing practices on the macronutrient composition of citrus leaves in Israel. Ktavim [Israel] **6**:17–33.

HILGEMAN, R. H. 1941. Nitrogen uptake by grapefruit trees in the Salt River Valley. Proc. Amer. Soc. Hort. Sci. **39**:119–24.

——— 1957. Response of orange trees growing in the Salt River Valley of Arizona to chelated iron compounds. Jour. Rio Grande Val. Hort. Soc. **11**:14–20.

HILGEMAN, R. H., W. H., FULLER, L. F. TRUE, G. C. SHARPLES, and P. F. SMITH. 1970. Lithium toxicity in 'Marsh' grapefruit in Arizona. Jour. Amer. Soc. Hort. Sci. **95**:248–51.

HILGEMAN, R. H., and G. C. SHARPLES. 1968. Manganese deficiency in grapefruit in Arizona. Israel Jour. Agr. Res. **18**:187–91.

HILGEMAN, R. H., J. G. SMITH, and G. E. DRAPER. 1939. A preliminary note on nitrogen assimilation by citrus trees. Proc. Amer. Soc. Hort Sci. 37:58–61.

HILGEMAN, R. H., and C. W. VAN HORN. 1955. Citrus growing in Arizona. Univ. Ariz. Agr. Exp. Sta. Bul. **258** (rev.). 35 pp.

HOAGLAND, D. R. 1919. Relation of the concentration and reaction of the nutrient medium to the growth and absorption of the plant. Jour. Agr. Res. **18**:73–117.

HODGSON, J. F., R. M. LEACH, JR., and W. H. ALLAWAY. 1962. Micronutrients and animal nutrition. Micronutrients in soils and plants in relation to animal nutrition. Jour. Agr. Food Chem. **10**:171–74.

HOLEVAS, C. D. and S. D. DEMETRIADES. 1963. Degats causes aux agrumes par la toxicite des chlorures. Ann. Inst. Phytopath [Benaki] (n.s.) **5**:135–48.

IMPEY, R. L., and W. W. JONES. 1960. Rate of absorption of urea by intact leaves of Washington navel orange. Proc. Amer. Soc. Hort. Sci. **76**:181–85.

INNES, R. F. 1946. Fertilizer experiments on grapefruit in Jamaica. Trop. Agr. [Trinidad] **23**:131–33.

IWASAKI, T., and T. SHICHIJO. 1962. Toxicity of biuret in urea to citrus. Bul. Hort. Res. Sta. Okitsu, Ser. B. **1**:17–27.

JACOB, A. 1958. Magnesium. The fifth major plant nutrient. Translated from German by Dr. Norman Walker. Staples Press Limited, London. 159 pp.

JACOBY, B. 1961. Conditions responsible for the appearance of magnesium deficiency in citrus groves on Israel's Mediterranean coast. Israel Jour. Agr. Res. (Ktavim) **11**:173–78.

JOHNSTON, J. C. 1933. Zinc sulfate promising new treatment for mottle leaf. Calif. Citrog. **18**:107, 116–18.

JONES, W. W. 1954. Biuret toxicity of urea foliage sprays on citrus. Science **120**:499–500.

JONES, W. W., W. P. BITTERS, and A. H. FINCH. 1944. The relation of nitrogen absorption to nitrogen content of fruit and leaves in citrus. Proc. Amer. Soc. Hort. Sci. **45**:1–4.

JONES, W. W., and C. B. CREE. 1953. Fertilizer placement for citrus. Calif. Citrog. **38**:363.

JONES, W. W., C. B. CREE, and T. W. EMBLETON. 1961. Some effects of nitrogen sources and cultural practices on water intake by soil in a Washington navel orange orchard and on fruit production, size, and quality. Proc. Amer. Soc. Hort. Sci. **77**:146–54.

JONES, W. W. and T. W. EMBLETON. Unpublished data on file at Dept. of Plant Sciences, Univ. of Calif. Citrus Res. Center, Riverside, Calif.

——— 1954*a*. Nitrogen fertilizer and orange production. Calif. Citrog. **39**:120, 122.

——— 1954*b*. Urea sprays for oranges. Calif. Citrog. **39**: 252.

——— 1956. The relation of potassium to fruit size in oranges. Better Crops with Plant Food **40**(4):22–25.

——— 1959. The visual effect of nitrogen nutrition on fruit quality of Valencia oranges. Proc. Amer. Soc. Hort. Sci. **73**:234–36.

——— 1960*a*. Leaf analysis—nitrogen control program for oranges. Calif. Citrog. **45**:349.

——— 1960*b*. Nitrogen-grade-packout relations in Valencias. Calif. Citrog. 45:241–42.

——— 1964. Relation of nitrogen nutrition to lemon production. Calif. Citrog. 49:267, 276.

——— 1967. Yield and fruit quality of 'Washington' navel orange trees as related to leaf nitrogen and nitrogen fertilization. Proc. Amer. Soc. Hort. Sci. 91:138–42.

——— 1968. Some guidelines for the use of nitrogen leaf analysis for citrus. Calif. Citrog. **54**:4.

JONES, W. W., T. W. EMBLETON, S. B. BOSWELL, G. E. GOODALL, and E. L. BARNHART. 1970. Nitrogen

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rate effects on lemon production, quality and leaf nitrogen. Jour. Amer. Soc. Hort. Sci. **95**:46–49.

JONES, W. W., T. W. EMBLETON, S. B. BOSWELL, M. L. STEINACKER, B. W. LEE, and E. L. BARNHART. 1963. Nitrogen control program for oranges and high sulfate and/or high boron. Calif. Citrog. **48**: 107, 128–29.

JONES, W. W., T. W. EMBLETON, and C. B. CREE. 1962. Temperature effects on acid, brix in Washington navel oranges. Calif. Citrog. **47**:132–34.

JONES, W. W., T. W. EMBLETON, M. J. GARBER, and C. B. CREE. 1967. Creasing of orange fruit. Hilgardia **38**:231–44.

JONES, W. W., T. W. EMBLETON, and G. E. GOODALL. 1955. Urea as a source of nitrogen for citrus—Biuret tolerance levels. Citrus Leaves **35**(11):12.

JONES, W. W., T. W. EMBLETON, and K. W. OPITZ. 1971. Effects of foliar applied Mg on yield, fruit quality and macronutrients of 'Washington' navel orange. Jour. Amer. Soc. Hort. Sci. **96**:68–70.

JONES, W. W., T. W. EMBLETON, K. W. OPITZ, M. L. STEINACKER, and C. B. CREE. 1959. Tulare County navels. Nitrogen-yield-quality relations. Calif. Citrog. **45**:40, 56–58.

JONES, W. W., T. W. EMBLETON, and M. L. STEINACKER. 1957. Nitrogen fertilizers as related to orange quality and yield. Calif. Citrog. **43**:3, 12.

JONES, W. W., J. P. MARTIN, and W. P. BITTERS. 1957. Influence of exchangeable sodium and potassium in the soil on the growth and composition of young lemon trees on different rootstocks. Proc. Amer. Soc. Hort. Sci. **69**:189–96.

JONES, W. W., and E. R. PARKER. 1947. Ascorbic acid-nitrogen relations in navel orange juice, as affected by fertilizer applications. Proc. Amer. Soc. Hort. Sci. **50**:195–98.

——— 1949*a*. Application of urea to foliage of orange trees. Calif. Citrog. **34**:463.

——— 1949*b*. Effects of nitrogen, phosphorus, and potassium fertilizers and of organic materials on the composition of Washington navel orange juice. Proc. Amer. Hort. Sci. **53**:91–102.

JONES, W. W., and P. F. SMITH. 1964. Nutrient deficiencies in citrus. *In:* Sprague, H. B. (ed.). Hunger signs in crops. Third edition. Chap. 11:359–414. David McKay Co., New York, N.Y.

JONES, W. W., and M. L. STEINACKER. 1953. Leaf sprays of urea as a source of nitrogen for citrus trees. Calif. Citrog. **38**:84, 107.

JONES, W. W., C. W. VAN HORN, and A. H. FINCH. 1945. The influence of nitrogen nutrition of the tree upon the ascorbic acid content and other chemical and physical characteristics of grapefruit. Univ. Ariz. Agr. Expt. Sta. Tech. Bul. **106**:456–84.

KAJIURA, M. 1967. The fruit industry of Japan, South Korea, and Taiwan. Proc. VII Intern. Hort. Cong. **4**:403–25.

KLOTZ, L. J., E. C. CALAVAN, and T. A. DEWOLFE. 1956. Leaf drop and copper spray damage to citrus. Citrus Leaves **36**(3):6–7, 26.

KOO, R. C. J. 1961. Potassium nutrition and fruit splitting in Hamlin orange. Univ. Fla. Agr. Expt. Sta. Ann. Rept. **1961**:223–24.

——— 1962. The use of leaf, fruit, and soil analysis in estimating potassium status of orange trees. Proc. Fla. State Hort. Soc. **75**:67–72.

——— 1972. A comparison of magnesium sources for citrus. Proc. Soil and Crop Sci. Fla. **31**:137:40. Bul. 271: 14 pp.

KOO, R. C. J., and D. V. CALVERT. 1966. Magnesium oxides as sources of magnesium for citrus. Proc. Fla. State Hort. Soc. **79**:7–12.

KOO, R. C. J., H. J. REITZ, and J. W. SITES. 1958. A survey of the mineral nutrition status of Valencia orange in Florida. Univ. Fla. Agr. Expt. Sta. Bul. **604**:59 pp.

KOO, R. C. J., and W. F. SPENCER. 1959. Potassium studies. Univ. Fla. Agr. Expt. Sta. Ann. Rept. **1959**:208–09.

KOO, R. C. J., and T. W. YOUNG. 1969. Correcting magnesium deficiency of limes grown on calcareous soils with magnesium nitrate. Proc. Fla. State Hort. Soc. **82**:274–78.

KOTO, M., S. TAKESHITA, and T. NAKAJIMA. 1963. Leaf analysis of Unshiu orange. VI. (1) The effects of Mn fertilizers on Mn-deficient trees. (2) The effects of Mg fertilizers on Mg-deficient trees of the early strain (Wase Unshiu). Kanagawa Hort. Expt. Sta. Bul. **11**:11–19.

KUYKENDALL, J. R., R. H. HILGEMAN, and C. W. VAN HORN. 1957. Response of chlorotic citrus trees in Arizona to soil applications of iron chelates. Soil Sci. **84**:77–86.

LABANAUSKAS, C. K. Unpublished data on file at Dept. of Plant Sciences, Univ. of Calif. Citrus Res. Center, Riverside, Calif.

——— 1962. Correction of manganese deficiencies in grapefruit trees by foliar sprays in desert areas of southern California. Proc. Amer. Soc. Hort. Sci. **80**:268–73.

——— 1969. Interactions of nutrients in Valencia orange leaves as affected by the composition of manganese, zinc, and urea sprays. Hilgardia **39**: 507–13.

LABANAUSKAS, C. K., W. W. JONES, and T. W. EMBLETON. 1962. Effects of nitrogen, phosphorus, potassium, limestone, gypsum, and manure soil applications on soil pH and on macro- and micronutrient concentrations in Washington navel orange leaves. Proc. Amer. Soc. Hort. Sci. **80**:259–67.

——— 1963. Effects of foliar applications of manganese, zinc, and urea on yield and fruit quality of Valencia oranges, and nutrient concentrations in the leaves, peel, and juice. Proc. Amer. Soc. Hort. Sci. **82**:142–53.

——— 1969. Low residue micronutrient nutritional sprays for citrus. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. **3**:1535–42. Univ. of Calif. Riverside, Calif.

LABANAUSKAS, C. K., and R. E. PUFFER. 1964. Effects of foliar applications of manganese, zinc, and urea on Valencia orange yield and foliage composition. Proc. Amer. Soc. Hort. Sci. **84**:158–64.

LANGENEGGER, W. 1958. Nitrogen is essential—but be careful. Farming So. Africa **34**(9):49.

LENZ, F. 1967. Der einfluss unterschiedlich hoher stickstoffgaben auf die entwicklung einiger qualitätsmerkmale von 'Valencia Late' orangen (*Citrus sinensis* L. Osbeck). Gartenbauwiss. **32**:181–92.

LEONARD, C. D. 1969. A comparison of soil and spray applications of four manganese sources for control of manganese deficiency in Valencia orange trees. Proc. Fla. State Hort. Soc. **82**:12–20.

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Original from PENN STATE

LEONARD, C. D., and I. STEWART. 1952. Correction of iron chlorosis in citrus with chelated iron. Proc. Fla. State Hort. Soc. **65**:20–24.

——— 1960. Yellow-vein in citrus. Proc. Fla. State Hort. Soc. **73**:69–79.

LEONARD, C. D., I. STEWART, and G. EDWARDS. 1958. Soil application of zinc for citrus on acid sandy soil. Proc. Fla. State Hort. Soc. **71**:99–106.

LEROUX, J. C., and P. A. CROUS. 1938. Effect of fertilizers on "creasing" of Mediterranean sweet oranges. Farming So. Africa **13**:66–68, 85.

LEYDEN, R. F. 1966. Timing and rate of nitrogen fertilizer application for Texas citrus orchards. Jour. Rio Grande Val. Hort. Soc. **20**:74–78.

LILLELAND, O., J. G. BROWN, and J. P. CONRAD. 1942. The phosphate nutrition of fruit trees. III. Comparison of fruit tree and field crops responses on a phosphate deficient soil. Proc. Amer. Soc. Hort. Sci. **40**:1–7.

LOMBARD, P. B., G. A. CAHOON, W. W. JONES, and M. J. GARBER. 1962. The effect of nitrogen fertilization and cultural treatments on soil moisture relationships of mature Washington navel orange trees. Proc. Amer. Soc. Hort. Sci. **81**:209–17.

LYNCH, S. J., S. GOLDWEBER, and C. RICH. 1953. Some effects of nitrogen, phosphorus and potassium fertilization on the constituents of Persian lime fruits. Proc. Fla. State Hort. Soc. **66**:224–27.

MCCOLLOCH, R. C., F. T. BINGHAM, and D. G. ALDRICH. 1957. Relation of soil potassium and magnesium to magnesium nutrition of citrus. Soil Sci. Soc. Amer. Proc. **21**:85–88.

MARTIN, J. P. 1950. Effect of soil fungi on germination of sweet orange seeds and development of the young seedlings. Soil Sci. Soc. Amer. Proc. **14**:184–88.

MARTIN, J. P., W. P. BITTERS, and J. O. ERVIN. 1959. Influence of exchangeable Na, and K and of excess lime on growth and chemical composition or trifoliate orange seedlings. Proc. Amer. Soc. Hort. Sci. **74**:308–12.

MARTIN, J. P., and H. D. CHAPMAN. 1951. Volatilization of ammonia from surface-fertilized soils. Soil Sci. **71**:25–34.

MARTIN, J. P., J. O. ERVIN, and R. A. SHEPHERD. 1961. Influence of exchangeable Na and K at different base-saturation levels on growth and composition of citrus plants. Soil Sci. **91**:273–79.

MARTIN, J. P., R. B. HARDING, and W. S. MURPHY. 1953. Effects of various soil exchangeable cation ratios on growth and chemical composition of citrus plants. Soil Sci. **76**:285–95.

MARTIN, J. P., and A. L. PAGE. 1962. Influence of soil base saturation (pH) on growth and chemical composition of citrus seedlings. So. African Citrus Jour. **344**:9, 11, 13, 15, 17–18.

——— 1965. Influence of high and low exchangeable Mg and Ca percentages at different degrees of base saturation on growth and chemical composition of citrus plants. Plant and Soil **22**:65–80.

MARTIN, J. P., and S. J. RICHARDS. 1959. Influence of exchangeable hydrogen and calcium, and of sodium, potassium and ammonium at different hydrogen levels on certain physical properties of soils. Soil Sci. Soc. Amer. Proc. 23:335–38.

MARTIN, J. P., and S. D. VAN GUNDY. 1963. Influence of soil phosphorus level on the growth of sweet orange seedlings and the activity of the citrus nematode (*Tylenchulus semipenetrans*). Soil Sci. **96**: 128–35.

MARTIN, W. E. 1939*a*. Some effects of cultural practices upon tree composition, yield and quality of Marsh grapefruit in Arizona. Proc. Amer. Soc. Hort. Sci. **37**:68–75.

——— 1939*b*. Nitrogen nutrition in relation to yield and quality of grapefruit. Plant Physiol. **14**:606–07.

MAXWELL, N., and A. DACUS. 1958. Fertilizing red grapefruit in sod culture. Jour. Rio Grande Val. Hort. Soc. **12**:19–21.

MILLER, E. C. 1938. Plant Physiology, Second edition. McGraw-Hill Book Co., Inc., New York and London. 1201 pp.

MORRIS, A. A. 1938. Some observations on the effects of boron treatment in the control of "hard fruit" in citrus. Jour. Pomol. and Hort. Sci. **16**:167–81.

NAUDÉ, C. J. 1954. Fertilisation of citrus. Application of macro-elements. Farming So. Africa **29**:351–57, 371.

——— 1958. The influence of rootstock and temperature on nutrient accumulation in citrus grown in solution culture. *In:* Wallace, A. (ed.). Tree physiology studies at U.C.L.A., Special Rept., No. 1. Pp. 104–24. Dept. Hort. Sci., Univ. Calif., Los Angeles, Calif.

OBERHOLZER, P. C. J. 1947. The present status of citrus nutrition in South Africa. So. African Dept. Agr. Bul. **271**: 14 pp.

OPITZ, K. W., and R. G. PLATT. 1967. Boron deficiency in central California. Calif. Citrog. **52**:474.

OPPENHEIMER, H. R. and LOTTIE HEYMANN-HERSCHBERG. 1954. Effects of nitrogen fertilizing on soil, growth, leaf composition, and yield in Shamouti orange groves. Israel Jour. Agr. Res. (Ktavim) **5**(1):5–17.

PAGE, A. L., T. J. GANJE, T. W. EMBLETON, and W. W. JONES. 1969. Soil factors influencing the correction of potassium deficiencies on citrus in California. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. **3**:1605–12. Univ. of Calif., Riverside, Calif.

PAGE, A. L., J. P. MARTIN, and T. J. GANJE. 1963. Foliar absorption and translocation of potassium by citrus. Proc. Amer. Soc. Hort. Sci. **82**:165–71.

PARKER, E. R. 1934. Experiments on the treatment of mottle-leaf of citrus trees. Proc. Amer. Soc. Hort. Sci. **31**:98–107.

——— 1937. Effect of zinc applications on the crop of grapefruit trees affected with mottle-leaf. Hilgardia **11**:35–53.

PARKER, E. R., and L. D. BATCHELOR. 1942. Effects of fertilizers on orange yields. Univ. Calif. Agr. Expt. Sta. Bul. **673**: 39 pp.

PARKER, E. R., and H. JENNY. 1945. Water infiltration and related soil properties as affected by cultivation and organic fertilization. Soil Sci. **60**:353–76.

PARKER, E. R., and W. W. JONES. 1950. Orange fruit sizes in relation to potassium fertilization in a long-term experiment in California. Proc. Amer. Soc. Hort. Sci. **55**:101–13.

——— 1951. Effects of fertilizers upon the yields, size and quality of orange fruits. Univ. Calif. Agr. Expt. Sta. Bul. **722**: 58 pp.

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Original from PENN STATE

PEECH, M. 1939. Chemical studies on soils from Florida citrus groves. Univ. Fla. Agr. Expt. Sta. Tech. Bul. **340:** 50 pp.

PHILLIPPE, J. 1958. Report on preliminary trial with mineral fertilizer on citrus in Belgian Congo. Bul. Inf. I.N.E.A.C. **7**:67–69.

PLATT, R. G. 1968. Micronutrient deficiencies of citrus. Univ. Calif. Agr. Expt. Sta. Leaf. (Rev.) **115:** 8 pp.

PRATT, P. F., and R. B. HARDING. 1957*a*. Effect of fertilizers on loss of magnesium from soil. Citrus Leaves **37**(2):10.

——— 1957*b*. Decreases in exchangeable magnesium in an irrigated soil during 28 years of differential fertilization. Agron. Jour. **49**:419–21.

PRATT, P. F., R. B. HARDING, W. W. JONES, and H. D. CHAPMAN. 1959. Chemical changes in an irrigated soil during 28 years of differential fertilization. Hilgardia **28**:381–420.

PRATT, P. F., W. W. JONES, and F. T. BINGHAM. 1957. Magnesium and potassium content of orange leaves in relation to exchangeable magnesium and potassium in the soil at various depths. Proc. Amer. Soc. Hort. Sci. **70**:245–51.

PRATT, P. F., W. W. JONES, and H. D. CHAPMAN. 1956. Changes in phosphorus in an irrigated soil during 28 years of differential fertilization. Soil Sci. **82:** 295–306.

PRATT, P. F., W. W. JONES, and V. E. HUNSAKER. 1972. Nitrate in deep soil profiles in relation to fertilizer rates and leaching volume. Jour. Environ. Quality **1**:97–102.

PRATT, R. M. (ed.). 1958. Florida guide to citrus insects, diseases and nutritional disorders in color. Univ. Fla. Agr. Expt. Sta., Gainesville. 191 pp.

RAPALLO, A. J. 1956. Fertilizing orange trees. (Abstract.) Fruits Outre Mer **11**(5):1097.

RASMUSSEN, G. K., and P. F. SMITH. 1958. Effects of fertilizer rate, rootstock, and leaf age on the level of sulfur in citrus leaves. Proc. Amer. Soc. Hort. Sci. **71**:241–47.

——— 1959. Pot studies on the effect of superphosphates on the growth of citrus seedlings. Proc. Fla. State Hort. Soc. **72**:71–75.

REESE, R. L. 1967. Improved fertilizer material gives reduced perchlorate toxicity symptoms. Proc. Fla. State Hort. Soc. **80**:15–19.

REITZ, H. J. 1956. Timing fertilization of citrus in the Indian River area. Proc. Fla. State Hort. Soc. **69:** 58–64.

——— 1961. Citrus needs adequate nutrition. Better Crops with Plant Food. **45**(4):10–14, 31.

REITZ, H. J., and R. R. HUNZIKER. 1961. A nitrogen rate and arsenic spray experiment on Marsh grapefruit in the Indian River area. Proc. Fla. State Hort. Soc. **74**:62–67.

REITZ, H. J., and R. C. J. KOO. 1960. Effect of nitrogen and potassium fertilization on yield, fruit quality, and leaf analysis of Valencia orange. Proc. Amer. Soc. Hort. Sci. **75**:244–52.

REITZ, H. J., C. D. LEONARD, I. STEWART, R. C. J. KOO, C. A. ANDERSON, R. L. REESE, D. V. CALVERT, and P. F. SMITH. 1972. Recommended fertilizers and nutritional sprays for citrus. Univ. Fla. Agr. Expt. Sta. Bul. **536C**:26 pp.

REITZ, H. J., and W. T. LONG. 1952. Mineral composition of citrus leaves from the Indian River area of Florida. Proc. Fla. State Hort. Soc. **65**:32–38.

REITZ, H. J., and N. F. SHIMP. 1953. Copper oxide as a soil amendment for citrus. Proc. Fla. State Hort. Soc. **66**:37–42.

REUTHER, W., and C. L. CRAWFORD. 1946. Effect of certain soil and irrigation treatments on citrus chlorosis in a calcareous soil: I. Plant responses. Soil Sci. **62**:477–91.

REUTHER, W., F. E. GARDNER, P. F. SMITH, and W. R. ROY. 1949. Phosphate fertilizer trials with oranges in Florida. I. Effects on yield, growth, and leaf and soil composition. Proc. Amer. Soc. Hort. Sci. **53**:71–84.

REUTHER, W., and P. F. SMITH. 1950. A preliminary report on the relation of nitrogen, potassium, and magnesium fertilization to yield, leaf composition, and the incidence of zinc deficiency in oranges. Proc. Amer. Soc. Hort. Sci. **56**:27–33.

——— 1952*a*. Iron chlorosis in Florida citrus groves in relation to certain soil constituents. Proc. Fla. State Hort. Soc. **65**:62–69.

——— 1952*b*. Relation of nitrogen, potassium, and magnesium fertilization to some fruit qualities of Valencia orange. Proc. Amer. Soc. Hort. Sci. **59**:1–12.

——— 1953. Effects of high copper content of sandy soil on growth of citrus seedlings. Soil Sci. **75**:219–24.

——— 1954. Effect of method of timing nitrogen fertilization on yield and quality of oranges. Proc. Fla. State Hort. Soc. **67**:20–26.

REUTHER, W., P. F. SMITH, and G. K. SCUDDER, JR. 1953. Relation of pH and soil type to toxicity of copper to citrus seedlings. Proc. Fla. State Hort. Soc. **66:** 73–80.

REUTHER, W., P. F. SMITH, G. K. SCUDDER, JR, and G. HRNCIAR. 1957. Responses of Valencia orange trees to timing, rates, and ratios of nitrogen fertilization. Proc. Amer. Soc. Hort. Sci. **70**:223–36.

REUTHER, W., P. F. SMITH, and A. W. SPECHT. 1949. A comparison of the mineral composition of Valencia orange leaves from the major producing areas of the United States. Proc. Fla. State Hort. Soc. **62:** 38–45.

RODNEY, R. 1964. Arizona citrus notes. Calif. Citrog. **49:** 210–12.

RODNEY, D. R. 1969. Arizona citrus notes. Calif. Citrog. **54**:188–89.

RODNEY, D. R., and G. C. SHARPLES. 1961. Responses of Lisbon lemon trees to applications of nitrogen, phosphate, and manure. Proc. Amer. Soc. Hort. Sci. **78**:181–85.

RODRIGUEZ, O., and S. MOREIRA. 1969. Citrus nutrition—20 years of experimental results in the state of Sao Paulo, Brazil. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. **3**:1569–78. Univ. of Calif., Riverside, Calif.

ROSSELET, F., S. V. HEFER, K. A. W. HELFF, W. LANGENEGGER, and F. H. LEROUX. 1962. Yield and quality responses of Valencia orange trees to fertilisation. So. African Jour. Agr. Sci. **5**:351–72.

ROSSELET, F., K. A. W. HELFF, and W. LANGENEGGER. 1963. A comparison of nitrogen sources under two cultural practices for Valencia orange trees. So. African Jour. Agr. Sci. **6**:701–18.

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ROY, W. R. 1943. Studies of boron deficiency in grapefruit. Proc. Fla. State Hort. Soc. **56**:38–43.

ROY, W. R., and F. E. GARDNER. 1945. Seasonal absorption of nutrient ions by orange trees in sand culture. Proc. Fla. State Hort. Soc. **58**:25–36.

SABEY, B. R., W. V. BARTHOLOMEW, R. SHAW, and J. PESEK. 1956. Influence of temperature on nitrification in soils. Soil Sci. Soc. Amer. Proc. **20**:357–60.

SAKAMOTO, T., and S. OKUCHI. 1963. Effect of a six-year potassium fertilization on yield, fruit quality, and leaf analysis of bearing Satsuma orange. Jour. Jap. Soc. Hort. Sci. **32**:256–64.

SATŌ, K., M. ISHIHARA, M. SUEHIRO, A. KURIHARA, and I. TABUCHI. 1962. Studies on the boron deficiency and excess in citrus. Part 1. Leaf and soil analyses in boron-deficient citrus orchards and seasonal changes in the chemical composition in *Citrus natsudaidai* leaves. (1957–1958.) Bul. Hort. Res. Sta., Hiratsuka, Ser. A., **1**:37–64.

SHARPLES, G. C., and R. H. HILGEMAN. 1969. Influence of differential nitrogen fertilization of production, trunk growth, fruit size and quality and foliage composition of 'Valencia' orange trees in central Arizona. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. **3**:1569–78. Univ. of Calif. Riverside, Calif.

SHAW, E. J. (ed.). 1965. Western fertilizer handbook. Fourth edition. Soil Improvement Committee, California Fertilizer Association, Sacramento, Calif. 200 pp.

SINGH, R. L. 1960. Studies on the effect of three levels of nitrogen on the growth and cropping of mandarins (*Citrus reticulata* Blanco) and sweet oranges (*Citrus sinensis* Osbeck) budded on different rootstocks. II. Effect of vigor. Hort. Advance **4**:127–37.

SITES, J. W. 1950. The effect of variable potash fertilization on the quality and production of Duncan grapefruit. Proc. Fla. State Hort. Soc. **63**:60–68.

SITES, J. W., and E. J. DESZYCK. 1952. Effect of varying amounts of potash on yield and quality of Valencia and Hamlin oranges. Proc. Fla. State Hort. Soc. **65**:92–98.

SITES, J. W., I. W. WANDER, and E. J. DESZYCK. 1953. The effect of fertilizer timing and rate of application on fruit quality and production of Hamlin oranges. Proc. Fla. State Hort. Soc. **66**:54–62.

——— 1961. The rate and timing of nitrogen for grapefruit on Lakeland fine sand. Proc. Fla. State Hort. Soc. **74**:53–57.

SMITH, P. F. 1954. Boron deficiency in Florida citrus groves. Proc. Fla. State Hort. Soc. **67**:69–73.

——— 1956. Effect of phosphate fertilization on root growth, soil pH, and chemical constituents at different depths in an acid sandy Florida citrus soil. Proc. Fla. State Hort. Soc. **69**:25–29.

——— 1957. Studies on the growth of citrus seedlings with different forms of nitrogen in solution cultures. Plant Physiol. **32**:11–15.

——— 1962*a*. Mineral analysis of plant tissues. Ann. Rev. Plant Physiol. **13**:81–108.

——— 1962*b*. A case of sodium toxicity in citrus. Proc. Fla. State Hort. Soc. **75**:120–24.

——— 1963. Nitrogen . . . in citrus fertilization. Citrus Indus. **44**(1):9–10.

——— 1964. Effect of potassium level and substrate lime on growth, fruit quality and nutritional status of Valencia orange trees. *In:* C. Bould, P. Prevot, and J. R. Magness (eds.). Plant analysis and fertilizer problems. IV. Pp. 332–43. Pub. by Amer. Soc. Hort. Sci., Lansing, Michigan.

——— 1966. Citrus nutrition. *In:* N. F. Childers (ed.). Temperate to tropical fruit nutrition. Pp. 174–207. Horticultural Publications, Rutgers Univ., New Brunswick, New Jersey.

——— 1967*a*. Nutritional responses of citrus grown in a humid climate. Proc. XVII Intern. Hort. Congr. (1966) **3**:197–214.

——— 1967*b*. Effect of soil placement, rate, and source of applied zinc on the concentration of zinc in Valencia orange leaves. Soil Sci. **103**:209–12.

——— 1967*c*. A comparison of three nitrogen sources on mature Valencia orange trees. Proc. Fla. State Hort. Soc. **80**:1–7.

——— 1969*a*. Nitrogen studies on grapefruit in Florida. *In:* H. D. Chapman (ed.). Proc. First Intern. Citrus Symp. **3**:1559–67. Univ. of Calif., Riverside, Calif.

——— 1969*b*. Nitrogen stress and premature leaf abscission in citrus. HortScience **4**:326–27.

——— 1971. Effects of time of application of N and K and of N rate on performance of nucellar 'Valencia' orange trees on two stocks. Jour. Amer. Soc. Hort. Sci. **96**:568–71.

SMITH, P. F., and G. K. RASMUSSEN. 1958. Relation of fertilization to winter injury of citrus trees. Proc. Fla. State Hort. Soc. **71**:170–75.

——— 1959. Field trials on the long-term effect of single applications of copper, zinc, and manganese on Florida sandy citrus soil. Proc. Fla. State Hort. Soc. **72**:87–92.

——— 1960. Relationship of fruit size, yield and quality of Marsh grapefruit to potash fertilization. Proc. Fla. State Hort. Soc. **73**:42–49.

——— 1961*a*. Effect of potash rate on growth and production of Marsh grapefruit in Florida. Proc. Amer. Soc. Hort. Sci. **77**:180–87.

——— 1968. Cu, Zn, and Mn status of soil and leaves ten years after differential soil applications of metals and lime in a young Valencia orange grove. Proc. Soil and Crop Sci. Fla. **28**:97–103.

——— 1961*b*. Effect of nitrogen source, rate, and pH on the production and quality of Marsh grapefruit. Proc. Fla. State Hort. Soc. **74**:32–38.

——— 1961*c*. Potassium-deficiency symptoms in grapefruit under field conditions in Florida. Proc. Amer. Soc. Hort. Sci. **78**:169–73.

SMITH, P. F., and W. REUTHER. 1949. Observations on boron deficiency in citrus. Proc. Fla. State Hort. Soc. **62**:31–37.

——— 1953. Mineral content of oranges in relation to fruit age and some fertilization practices. Proc. Fla. State Hort. Soc. **66**:80–85.

——— 1954. Citrus nutrition. *In:* N. F. Childers (ed.). Mineral nutrition of fruit crops. Pp. 223–56. Horticultural Publications, Rutgers Univ., New Brunswick, New Jersey.

——— 1955. Preliminary report on the effect of nitrogen source and rate and lime level on pH, root growth, and soil constituents in a Marsh grapefruit grove. Soil Sci. Soc. Fla. Proc. **15**:108–16.

SMITH, P. F., W. REUTHER, and F. E. GARDNER. 1949. Phosphate fertilizer trials with oranges in Florida.

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II. Effect on some fruit qualities. Proc. Amer. Soc. Hort. Sci. **53**:85–90.

SMITH, P. F., W. REUTHER, and G. K. SCUDDER, JR. 1953. Effect of differential supplies of nitrogen, potassium, and magnesium on growth and fruiting of young Valencia orange trees in sand culture. Proc. Amer. Soc. Hort. Sci. **61**:38–48.

SMITH, P. F., G. K. SCUDDER, JR., and G. HRNCIAR. 1963. Twenty years of differential phosphate application on Pineapple oranges. Proc. Fla. State Hort. Soc. **76**:7–12.

——— 1968. A comparison of nitrogen sources, rates, and placement on the performance of Pineapple orange trees. Proc. Fla. State Hort. Soc. **81**:25–29.

——— 1969. Nitrogen rate and time of application on the yield and quality of Marsh grapefruit. Proc. Fla. State Hort. Soc. **82**:20–25.

SMITH, P. F., and A. W. SPECHT. 1952. Heavy-metal nutrition in relation to iron chlorosis of citrus seedlings. Proc. Fla. State Hort. Soc. **65**:101–08.

SPENCER, W. F. 1954. Influence of cation-exchange reactions on retention and availability of cations in sandy soils. Soil Sci. **77**:129–36.

——— 1957. Distribution and availability of phosphates added to a Lakeland fine sand. Soil Sci. Soc. Amer. Proc. **21**:141–44.

——— 1958. The effects of phosphate and lime applications on growth, root distribution, and freeze injury of young grapefruit trees. Proc. Fla. State Hort. Soc. **71**:106–14.

——— 1960. Effects of heavy applications of phosphate and lime on nutrient uptake, growth, freeze injury, and root distribution of grapefruit trees. Soil Sci. **89**:311–18.

——— 1963. Phosphorus fertilization of citrus. Univ. Fla. Agr. Expt. Sta. Bul. **653**: 48 pp.

——— 1966. Effect of copper on yield and uptake of phosphorus and iron by citrus seedlings grown at various phosphorus levels. Soil Sci. **102**:296–99.

SPENCER, W. F., and R. C. J. KOO. 1962. Calcium deficiency in field-grown citrus trees. Proc. Amer. Soc. Hort. Sci. **81**:202–08.

SPENCER, W. F., and I. W. WANDER. 1960. A comparison of magnesium sources for young orange trees. Proc. Fla. State Hort. Soc. **73**:28–35.

STEWART, I., and C. D. LEONARD. 1951. Molybdenum deficiency in citrus. Proc. Fla. State Hort. Soc. **64**:51–53.

——— 1952*a*. Iron chlorosis—its possible causes and control. Citrus Mag. **14**(10):22–25.

——— 1952*b*. Chelates as sources of iron for plants growing in the field. Science **116**:564–66.

——— 1953. The cause of yellow tipping in citrus leaves. Citrus Indus. **34**(3):11–13.

——— 1957. Use of chelates in citrus production in Florida. Soil Sci. **84**:87–97.

——— 1958. Perchlorate toxicity. *In:* R. M. Pratt (ed.). Florida guide to citrus insects, diseases, and nutritional disorders in color. P. 68. Univ. Fla. Agr. Expt. Sta., Gainesville.

——— 1963. Effect of various salts on the availability of zinc and manganese to citrus. Soil Sci. **95**:149–54.

STEWART, I., C. D. LEONARD, and G. EDWARDS. 1955. Factors influencing the absorption of zinc by citrus. Proc. Fla. State Hort. Soc. **68**:82–88.

STEWART, I., C. D. LEONARD, and I. W. WANDER. 1961. Comparison of nitrogen rates and sources for Pineapple oranges. Proc. Fla. State Hort. Soc. **74**:75–79.

STEWART, I., and T. A. WHEATON. 1965. A nitrogen source and rate study on Valencia oranges. Proc. Fla. State Hort. Soc. **78**:21–26.

STEWART, I., T. A. WHEATON, and R. L. REESE. 1968. Collapse of Murcott citrus trees. HortScience **3**:230–31.

STOLZY, L. H., R. B. HARDING, and R. L. BRANSON. 1966. Foliar absorption of boron by sprinkler-irrigated citrus. Calif. Citrog. **51**:204–08.

STOLZY, L. H., S. D. VAN GUNDY, C. K. LABANAUSKAS, and T. E. SZUSZKIEWICZ. 1963. Response of *Tylenchulus semipenetran* infected citrus seedlings to soil aeration and temperature. Soil Sci. **96**:292–98.

TAIT, W. L. 1936. Some field tests with magnesium sources. Proc. Fla. State Hort. Soc. **49**:9–14.

TASAKI, K., Y. INOUE, and N. MATSUOKA. 1930. Fertilizer experiment with satsuma orange. Imp. Hort. Exp. Sta [Okitsu, Japan] Res. Bul. **13**:60 pp. [In Japanese, with English summary.]

VAN DER MERWE, A. J. 1949. Nitrogen nutrition of citrus in the nitrate and the ammonium form. I. Quantity and forms of inorganic nitrogen. Farming So. Africa **24**:243–45.

VAN DER MERWE, A. J., and F. G. ANDERSSEN. 1937. Chromium and manganese toxicity. Is it important in Transvaal citrus growing? Farming So. Africa **12**:439–40.

VAN NIEKERK, O. T. 1955. Report on the activities of the S. A. Cooperative Citrus Exchange Field Department, May, 1955. Citrus Grow. [So. Africa] **257**: 7–9, 12.

VOLK, G. M. 1959. Volatile loss of ammonia following surface application of urea to turf or bare soils. Agron. Jour. **51**:746–49.

——— 1961. Gaseous loss and mobility as factors in nitrogen efficiency. Soil Crop Sci. Soc. Fla. Proc. **21**: 261–68.

——— 1966. Efficiency of fertilizer urea as affected by method of application, soil moisture, and lime. Agron. Jour. **58**:249–52.

WAKSMAN, S. A. 1952. Soil microbiology. John Wiley & Sons, Inc., N. Y., Chapman & Hall, Ltd., London. 356 pp.

WALLACE, A., S. H. CAMERON, and P. A. T. WIELAND. 1955. Variability in citrus fruit characteristics, including the influences of position on the tree and nitrogen fertilization. Proc. Amer. Soc. Hort. Sci. **65**:99–108.

WALLACE, A., M. H. KIMBALL, R. T. MUELLER, and H. V. WELCH, JR. 1952. Influence of nitrogen fertilizers on orange trees and on the soil in the coastal zone of southern California. Proc. Amer. Soc. Hort. Sci. **59**:22–30.

WALLIHAN, E. F., and T. W. EMBLETON. 1961. Iron chlorosis. Calif. Citrog. **46**:67, 87, 89.

WALLIHAN, E. F., T. W. EMBLETON, G. E. GOODALL, R. G. PLATT, and R. W. SOUTHWICK. 1954. Orchard trials with iron chelates. Calif. Citrog. **40**:28, 30–31.

WALLIHAN, E. F., T. W. EMBLETON, and R. G. SHARPLESS. 1969. Studies of foliar sprays for correcting iron deficiency of citrus. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. 3:1525–29. Univ. of Calif., Riverside, Calif.

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WALLIHAN, E. F., and M. J. GARBER. 1968. Iron uptake by two citrus rootstock species in relation to soil moisture and $CaCO_3$. Agron. Jour. **60**:50–52.

WALLIHAN, E. F., M. J. GARBER, R. G. SHARPLESS, and WILMA L. PRINTY. 1961. Effects of soil oxygen deficit on iron nutrition of orange seedlings. Plant Physiol. **36**:425–28.

WALLIHAN, E. F., and LOTTE HEYMANN-HERSCHBERG. 1956. Some factors affecting absorption and translocation of zinc in citrus plants. Plant Physiol. **31**: 294–99.

WANDER, I. W. 1950. The effect of calcium phosphate accumulation in sandy soil on the retention of magnesium and manganese and the resultant effect on the growth and production of grapefruit. Proc. Amer. Soc. Hort. Sci. **55**:81–91.

——— 1951. Soil correlations. Composition of water draining from a grove area. Univ. Fla. Agr. Expt. Sta. Ann. Rept. **1951**:140–44.

——— 1954*a*. The total manganese, copper, and zinc content of soils used for citrus production in Florida. Soil Sci. Soc. Fla. Proc. **14**:27–36.

——— 1954*b*. Availability of phosphorus, potassium and magnesium from insoluble sources as indicated by the growth and leaf analysis of sweet orange seedlings. Proc. Fla. State Hort. Soc. **67**:60–66.

WEST, E. S. 1938. Zinc-cured mottle leaf in citrus induced by excess phosphate. Austral. Coun. Sci. Indus. Res. Jour. **11**(2):182–84.

WILLSON, A. E. 1951. Boron nutrition in citrus. Proc. Fla. State Hort. Soc. **64**:53–57.

WILLSON, A. E., and W. J. AREY. 1958. Potash relationships in commercial groves. Proc. Fla. State Hort. Soc. **71**:181–86.

WITTWER, S. H. 1967. Carbon dioxide and its role in plant growth. Proc. XVII Int. Hort. Congr. (1966). **3**: 311–22.

YOUNG, T. W., and W. T. FORSEE, JR. 1949. Fertilizer experiments with citrus on Davie mucky fine sand. Univ. Fla. Agr. Expt. Sta. Bul. **461**: 40 pp.

YOUNG, T. W., and R. C. J. KOO. 1967. Effects of nitrogen and potassium fertilization on Persian limes on Lakeland fine sand. Proc. Fla. State Hort. Soc. **80**: 337–42.

YUDA, E. 1970. Growth injury of citrus trees growing in the acid soils of Shizuoka Prefecture. Shizuoka Univ. Fac. Agr. Tech. Bul. **3**:84 pp. [In Japanese, with English summary.]

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CHAPTER 6

Leaf Analysis as a Diagnostic Tool and Guide to Fertilization

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METHODS OF DETERMINING fertilizer needs were discussed briefly in Chapter 5. A more detailed coverage of the use of leaf analysis is presented in this chapter.

The history of developmental research on use of plant analysis as a diagnostic tool is given in an excellent review by Goodall and Gregory (1947). Since that review important contributions to this subject have been made by Chapman (1966), Kenworthy and Martin (1966), Lundegärdh (1951), Reuther, Embleton, and Jones (1958), Shannon (1954), Smith (1962), and Ulrich (1948).

The development of plant analysis as a diagnostic tool for citrus has been made possible by the research of a considerable number of investigators. Their work has been reviewed by Bathurst (1943), Chapman (1968), Chapman and Brown (1941), Jones and Embleton (1967), Reuther and Smith (1954), and Smith (1966, 1967).

Sufficient progress has been made to use leaf analysis as a guide in planning fertilizer programs for some citrus varieties. The leaf analysis approach integrates the effects of many factors into one useful figure—the concentration of a given element in a specific type of leaf. Economic loss may occur in citrus even before the development of symptoms of deficiencies or excesses. Use of leaf analysis in planning a fertilizer program can help prevent such occurrences. If deficiencies or excesses do develop, leaf analysis can be used to good advantage in a "trouble-shooting" approach.

Deficiencies and excesses of a number of the essential elements produce characteristic symptoms in leaves or other plant parts. The use of symptomatology has been summarized by Chapman (1961). Symptoms of nutrient deficiencies of citrus are shown by Bryan (1961), Camp and Fudge (1939), Chapman (1968), Jones and Smith (1964), and Pratt (1958). Deficiencies of magnesium, iron, manganese, zinc, copper, molybdenum, and excesses of boron and sodium produce characteristic symptoms that can be helpful in diagnosis. However, when multiple deficiencies or excesses occur simultaneously, diagnosis is difficult, if not impossible, without leaf analysis.

Leaf analysis provides a common denominator for making parallel comparisons from solution, sand, soil, and field cultures, localities, years, and climates. It can also show whether or not applied elements are getting into the tree. This approach often provides an explanation for lack of response from an applied element.

The most beneficial use of leaf analysis may

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come from year-to-year use in a nutritional maintenance program. For example, leaf analysis can be used to good advantage in producing types of fruit suitable for specific marketing channels. An element does not have to be in a deficient or excess range insofar as yields are concerned to have a beneficial or adverse effect on some factors of fruit quality.

For leaf analysis to be most effective as a guide, other possible limiting factors that could restrict the performance of trees should be corrected. Such factors include insect and disease injury, nematode infestation, salinity in the soil, improper irrigation practices, poor soil structure, rodent damage, or mechanical injury. Leaf analysis is useful primarily in determining the trees' current nutritional status. However, an orchard record of leaf analysis for a number of years may foreshadow future trends.

Tree nutrition may be indirectly influenced by many factors. For example, if a root system is impaired by too much water in the soil, nematodes, or disease, deficiency symptoms of an element may appear. The deficiency symptoms may disappear when correction is made for the primary factor that impaired the root system.

Discussions in this chapter are based on the assumption that proper sampling techniques are used, samples are handled and prepared properly, and chemical analysis is accurate. Unless otherwise stated, results discussed are for leaves from nonfruiting terminals.

In discussing plant nutrition, the terms "deficiency" and "excess" must have a point of reference (Jones, 1966). The ranges for levels of nutrients in leaves for maximum production of fruit may be different from those for producing the greatest amount of vegetative growth, or largest size of fruit or the ranges associated with absence of deficiency symptoms on the leaves.

LEAF ANALYSIS STANDARDS

Leaf analysis standards for five- to seven-month-old, terminal, spring-cycle leaves from non-

Table 6–1
LEAF ANALYSIS GUIDE FOR DIAGNOSING NUTRIENT STATUS OF MATURE VALENCIA AND NAVEL ORANGE TREES*

Element	Unit (Dry Matter Basis)	Ranges†				
		Deficient	Low	Optimum	High	Excess
N	%	<2.2	2.2 to 2.3	2.4 to 2.6	2.7 to 2.8	>2.8
P	%	<0.09	0.09 to 0.11	0.12 to 0.16	0.17 to 0.29	>0.30
K‡	%	<0.40	0.40 to 0.69	0.70 to 1.09	1.10 to 2.00	>2.30?
Ca	%	<1.6?	1.6 to 2.9	3.0 to 5.5	5.6 to 6.9	>7.0?
Mg	%	<0.16	0.16 to 0.25	0.26 to 0.6	0.7 to 1.1	>1.2?
S	%	<0.14	0.14 to 0.19	0.2 to 0.3	0.4 to 0.5	>0.6
B	ppm	< 21	21 to 30	31 to 100	101 to 260	>260
Fe§	ppm	< 36	36 to 59	60 to 120	130 to 200?	>250?
Mn§	ppm	< 16	16 to 24	25 to 200	300 to 500?	>1000?
Zn§	ppm	< 16	16 to 24	25 to 100	110 to 200	>300
Cu§	ppm	<3.6	3.6 to 4.9	5 to 16	17 to 22?	>22?
Mo‖	ppm	<0.06	0.06 to 0.09	0.10 to 3.0	4.0 to 100	>100?
Cl	%	?	?	<0.3	0.4 to 0.6	>0.7
Na	%	?	?	<0.16	0.17 to 0.24	>0.25
Li	ppm	#	....	<3	3 to 35?	>35?
As	ppm	#	....	<1	1 to 5	>5?
F‖	ppm	#	....	<1 to 20	25 to 100	>100

* With the exception of nitrogen values this guide can be applied for grapefruit, lemon, and probably other commercial citrus varieties.

† Based on concentration of elements in five- to seven-month-old, spring-cycle leaves from nonfruiting terminals. Leaves selected for analysis should be free of obvious tipburn, insect or disease injury, mechanical damage, etc., and from trees that are not visibly affected by disease or other injury.

‡ Potassium ranges are for number of fruit per tree.

§ These values are not applicable for leaves that have been sprayed or dusted with the particular element in question. Leaves that have been sprayed or dusted with Fe, Mn, Zn or Cu may analyze high or excessive in these respective elements, but in the case of Fe, Mn or Zn the next growth cycle that appears may have values in the deficient range.

‖ From fruiting terminals (Chapman, 1960).

These elements are not known to be essential for growth of citrus.

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fruiting shoots of mature orange trees are given in table 6–1. These standards were established with the greatest economic return for fresh fruit as a point of reference. Since number of fruits per tree, fruit size, and fruit quality must all be considered, qualifications must be made. Qualifications concerning fruit for products are in order for certain situations. Where necessary, these qualifications are considered under the following discussions of the standards for each element. The extent of available diagnostic information for each element is also discussed.

Reitz *et al.* (1972) have listed for Florida conditions a satisfactory range of elements in four- to five-month old spring-flush leaves from nonfruiting twigs. Chapman (1960) gave leaf analysis standards for four- to ten-month old spring-cycle leaves from fruit-bearing terminals.

Results from both leaf analysis and a table of diagnostic values are limited in practical value unless a complete record is kept of the amount of each fertilizer element applied and of past leaf analyses. These form a basis for future adjustment in fertilizer rates.

Nitrogen

The orange leaf standards presented in table 6–1 were established largely from field experiments in the coastal and intermediate valleys of California and include general composite effects on fruit yield, size, and quality. However, with some minor adjustments noted below, they are widely applicable. In these experiments, fertilizers were applied as chemicals to the soil from mid-December through February, as manures in the fall, or as urea foliage sprays from January to May. If nitrogen is applied during or after the "June drop" period, unduly high nitrogen values may be found in the leaves even though fruit set was restricted because of low nitrogen during the flowering and "June drop" period. Under these conditions, use of nitrogen leaf analysis is less effective as a guide for nitrogen fertilization than for situations where nitrogen is applied before the bloom and fruit-setting period. In the latter situations an analysis of five- to seven-month-old spring-cycle leaves measures the "residual" nitrogen after the high demand period of rapid spring growth, flowering, and fruit setting.

Results from leaf analysis can be used more intelligently if one is aware of the specific effects of nitrogen on fruit yield, size, and quality. These specific effects are shown in figure 6–1.

Yield.—In the California experiments, no loss in volume yield has been associated with nitrogen values above 2.3 per cent (fig. 6–1). The standards in table 6–1 provide a small safety factor. In the Salt River Valley in Arizona, Sharples and Hilgeman (1969) reported that minimum leaf-nitrogen concentration associated with estimated optimum yield was about 2.2 per cent, which is slightly lower than the California data. Data of Reitz and Koo (1960) and Calvert (1970) indicate that the California standards apply to Valencia and Temple oranges growing in the calcareous soils of Eastern Florida. The California standards are apparently somewhat less applicable for oranges growing in the acid sands of Central Florida (Smith, 1967), although nitrogen leaf standards presented by Smith (1966) are practically the same as those in table 6–1.

In California the number of fruit harvested is generally increased and size of fruit decreased as nitrogen in leaves is increased from 2.3 to 3.0 per cent. The net effect is that volume yield is not affected in this range (fig. 6–1).

Lemon yields increase with percentages of nitrogen up to 2.5 in the youngest, fully-matured, terminal leaf from nonfruiting shoots sampled in the August-October period. In some of the vigorous cultivars of lemons, it has not been possible to attain the 2.5 per cent level of nitrogen even with very high rates of applied nitrogen (Jones and Embleton, 1964; Jones *et al.*, 1970). The observed effects of nitrogen on the quality of lemon fruits have been of little practical consequence.

Limited evidence indicates that the diagnostic leaf levels for nitrogen in grapefruit leaves are lower than those suggested for orange leaves. It appears that 2.0 to 2.2 per cent nitrogen in five- to seven-month-old, spring-cycle leaves of grapefruit in California desert areas is sufficient to maintain yield (Embleton, Jones, and Platt, 1969). Smith (1969) reported that about 2.5 per cent nitrogen in four- to five-month-old spring-cycle leaves maintained full yield potential and thrifty tree condition of grapefruit in central Florida.

Fruit Quality.—Nitrogen affects many factors of orange fruit quality as indicated in figure 6–1. The impact of these effects is not the same for fruit destined for processing as it is for fruit intended for the fresh-fruit market. The fruit quality problems in a specific orchard must also be considered if most effective use is to be made of results of nitrogen leaf analysis.

The amount of green color in the peel at harvest is primarily controlled by climate, but

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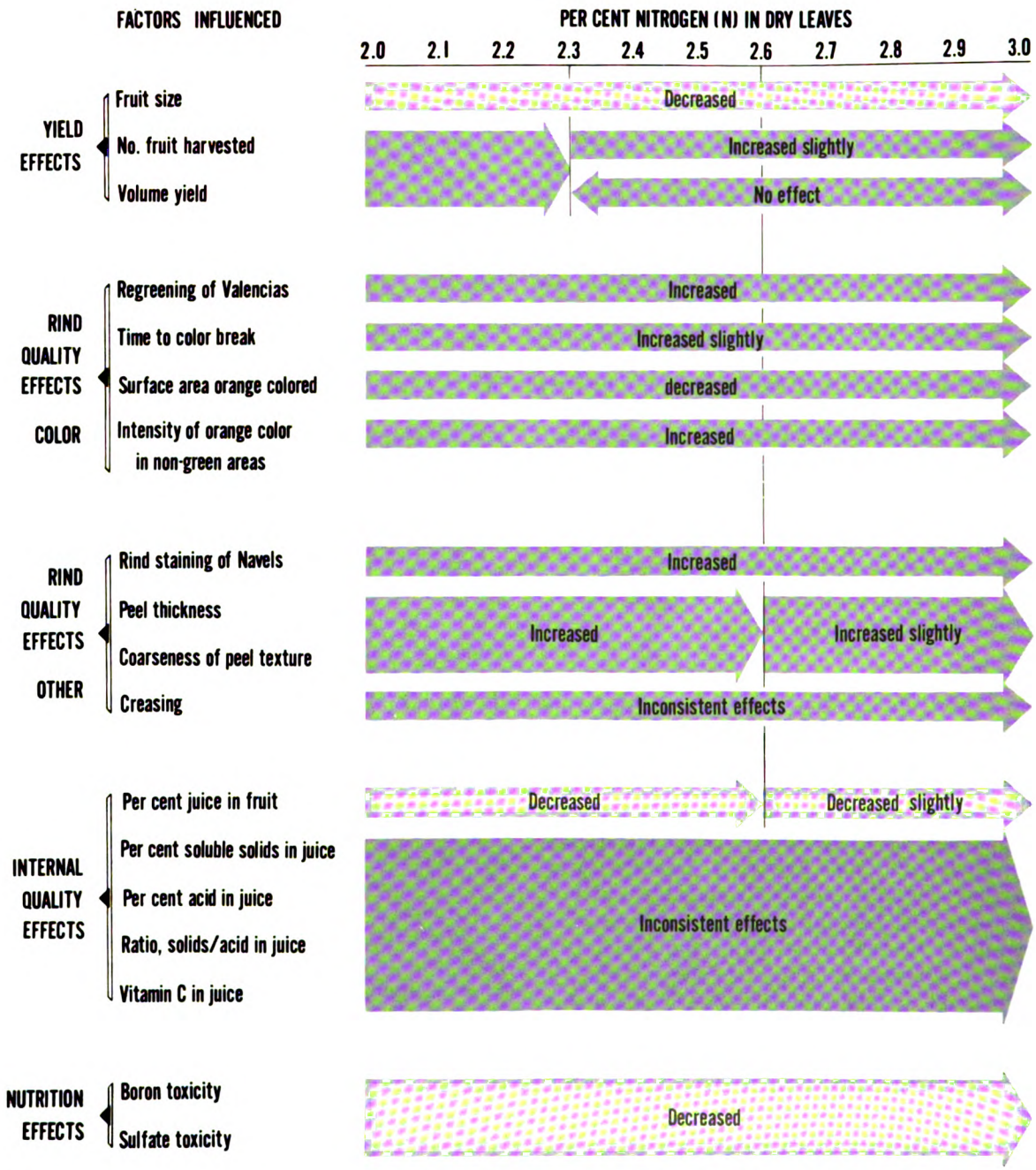

Fig. 6–1. Influence of the percentage of nitrogen in five- to seven-month-old, spring-cycle orange leaves from non-fruiting shoots upon factors of yield, rind quality, internal quality, and boron and sulfate nutrition. (From Jones, Embleton, and Platt, 1968).

nitrogen has an effect within a particular climate. In most subtropical citrus areas, green fruit color is not a problem with navels which are harvested in the winter or for fruit destined for processing. Time to color break of both navels and Valencias is delayed at higher levels of nitrogen nutrition (fig. 6–1). This delay can be a problem in fruit intended for the early season, fresh-fruit market.

Fruit color is a problem on Valencias harvested in the summer. Regreening can be reduced

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by reducing the nitrogen level in the tree. A tree relatively low in nitrogen in contrast to one high in nitrogen normally produces fruit with less regreening and a more uniform orange color on the surface; however, the orange color is not as intense (fig. 6–1). More regreening has also been associated with summer than early-spring or winter applications of nitrogen (Jones and Embleton, 1969).

Since the regreening problem, which is so important on Valencias for fresh-fruit market, is primarily a function of climate (Caprio, 1956) and can be partially prevented by nitrogen control, every year should be treated as a "bad"-color year. In "good"-color years the impact of nitrogen on market quality is not as great as in "bad"-color years.

Other factors that are adversely affected by an increase in the nitrogen level of both navels and Valencias are texture and thickness of the peel. In navels, rind staining (a post-harvest rupture of oil glands) is increased with an increase in nitrogen (fig. 6–1).

The percentage of juice in the fruit is normally reduced by an increase in nitrogen, while the nitrogen effects on total soluble solids, total acid, the ratio of total soluble solids to acid, and the amount of vitamin C in juice are inconsistent (fig. 6–1).

Although figure 6–1 indicates that the nitrogen level in the tree does not have consistent effects on creasing, most of the available data show that creasing is reduced slightly with an increase in the nitrogen rate (see vol. II, chap. 2). Late summer or fall nitrogen application to soil or foliage can result in less creasing than early spring applications; however, other factors of fruit quality will be adversely affected by such applications (Jones *et al.*, 1967).

Nutritional effects.—If boron or sulfur or both are at toxic levels in the trees as a result of the high concentrations of these two elements in irrigation water, and water of better quality cannot be obtained, nitrogen in orange leaves should be maintained above 2.6 per cent. The higher nitrogen level reduces the accumulation of boron and sulfur in the leaves, thus reducing the premature defoliation caused by boron and sulfur toxicity. This defoliation can cause a reduction in yield. Maintaining nitrogen above 2.6 per cent in the leaves may have an adverse effect on fresh-fruit quality, but under these specific conditions this sacrifice appears to be justified if yields are to be maintained (Jones *et al.*, 1963). Values of leaf nitrogen above 3.2 per cent may indicate a disturbance in the nutrition of another element, particularly phosphorus.

Phosphorus

The ranges for phosphorus in the leaves in table 6–1 were also established from field data under commercial conditions. As with nitrogen one set of common leaf analysis standards cannot be used effectively for all factors of fruit yield, size, and quality. The intensity of the various effects of phosphorus in relation to phosphorus level in leaves is shown in figure 6–2.

Yield.—Figure 6–2 indicates that numbers of orange fruit harvested and volume yield can be increased by increasing phosphorus level in the leaves up to about 0.13 per cent. This is based on a twelve-year experiment in California (Embleton *et al.*, 1971). The optimum range listed in table 6–1 is 0.12 to 0.16 per cent, which was what was indicated in experiments in other parts of the world and in less precise experiments in California. Perhaps the optimum range should be 0.13 to 0.16 per cent for some California conditions. As leaf levels have increased above about 0.165 per cent, reductions in yield have occurred.

A large decrease in fruit size can be expected as leaf phosphorus is increased from 0.10 to 0.15 per cent; further slight reductions in fruit size occur by increasing phosphorus above 0.15 per cent. Although the preponderance of evidence shows that an increase in the phosphorus level in orange trees was associated with smaller fruit, one experiment in South Africa (Rosselet *et al.*, 1962) showed that yield and fruit size were both increased by phosphorus fertilization.

Evidence from field experiments on lemon trees suggests that, for yield, the deficient and low levels of phosphorus in the youngest, fully-matured leaves, sampled in the August–October period are similar to those for oranges.

Fruit Quality.—Figure 6–2 indicates that with an increase in phosphorus in orange leaves the percentage of juice in the fruit, the amount of total soluble solids per ton of fresh fruit, and the ratio of total soluble solids to total acid in the juice increase; however, peel thickness, concentrations of total soluble solids, total acid, and ascorbic acid (vitamin C) in the juice decrease. The increase or decrease in these factors is greater in the lower ranges of leaf phosphorus than in the higher ranges. Regreening of Valencia oranges

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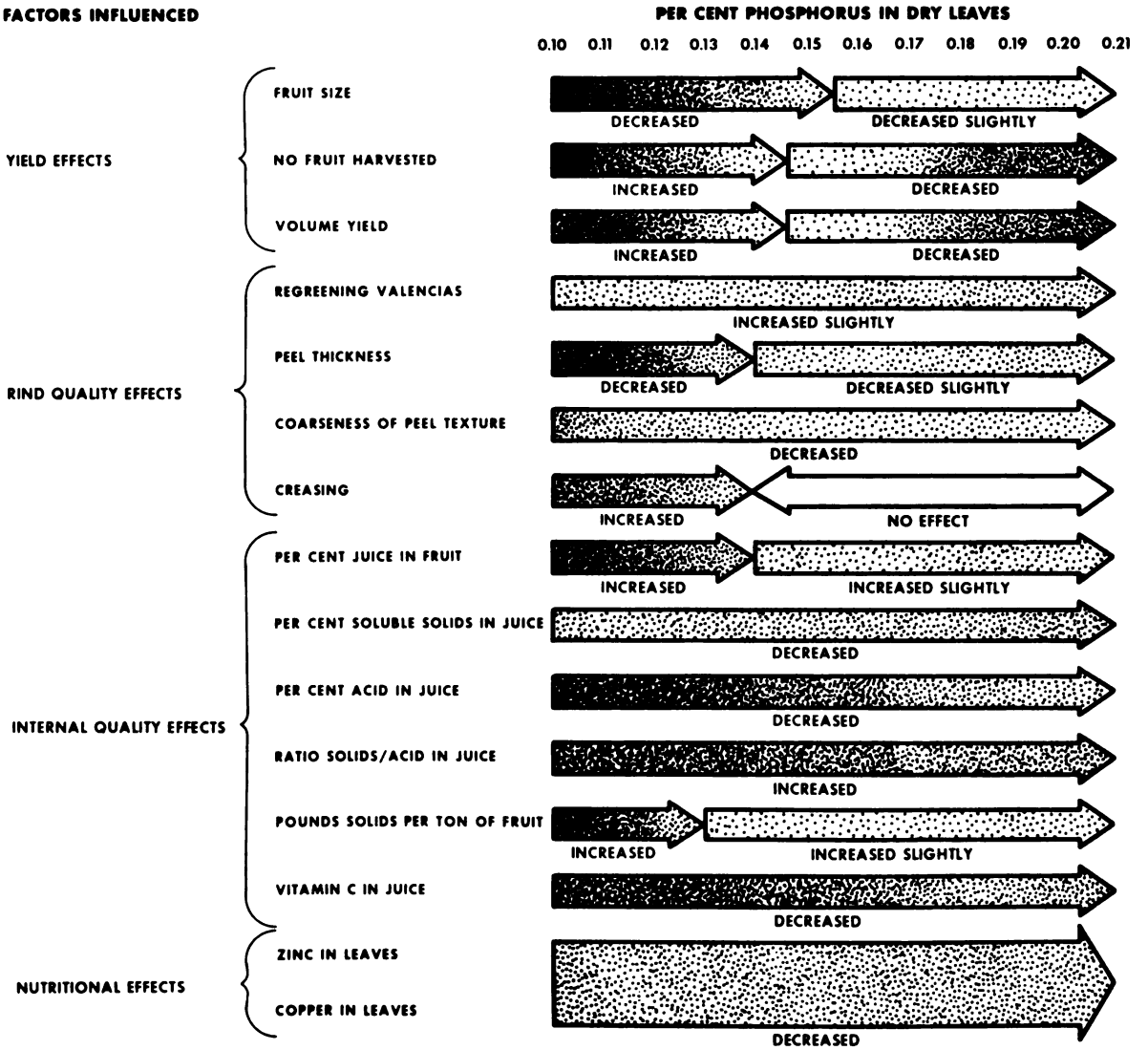

Fig. 6–2. Influence of the percentage of phosphorus in five- to seven-month-old, spring-cycle orange leaves from nonfruiting shoots upon factors of yield, rind quality, internal quality, and zinc and copper nutrition. Intensity of shading shows intensity of effect in indicated phosphorus ranges. (From Embleton *et al.*, 1971.)

increases slightly and rather uniformly throughout the increasing ranges of leaf phosphorus while coarseness of peel texture decreases.

Creasing becomes more prominent with an increase in leaf phosphorus up to about 0.14 per cent with no observable change above that level (Jones *et al.*, 1967). Experiments to date have shown practically no effect of phosphorus on lemon fruit quality, even in the deficient range limiting yield (Embleton, Jones, and Page, 1967).

Nutritional Effects.—Zinc and copper concentrations in orange leaves decrease rather uniformly throughout the ranges of increasing leaf phosphorus. These effects can, under some conditions, aggravate or induce a zinc or copper deficiency.

Potassium

Field data from experiments under commercial conditions were also used to establish the potassium ranges in table 6–1. *The ranges for potassium in table 6-1 are for numbers of fruit per tree.* However, important effects occur at potassium leaf levels above that necessary to maintain maximum fruit set as shown in figure 6–3. To make the most effective use of orange leaf analysis, one

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must consider the relative importance of the nutritional problems existing in a given orchard as well as the potential beneficial or adverse effects of potassium applications.

Yield.—At potassium levels below 0.7 per cent, orange fruit set may be reduced and preharvest drop of fruit increased, both of which reduce yield. An increase in potassium usually increases fruit size throughout the range of leaf potassium values found in the field in California. Because of the effects on fruit size, number of fruit harvested, and preharvest drop, an increase in potassium in the 0.3 to 0.7 per cent range has a strong effect on increasing volume yield. An increase in potassium above 0.7 per cent increases volume yield slightly because of the effects on fruit size (fig. 6–3).

The critical level of leaf potassium for yield of grapefruit and lemon appears to be about the same as that for the oranges in table 6–1. It is more difficult to obtain the proper leaf sample for lemons than for oranges or grapefruit in diagnosing the potassium status.

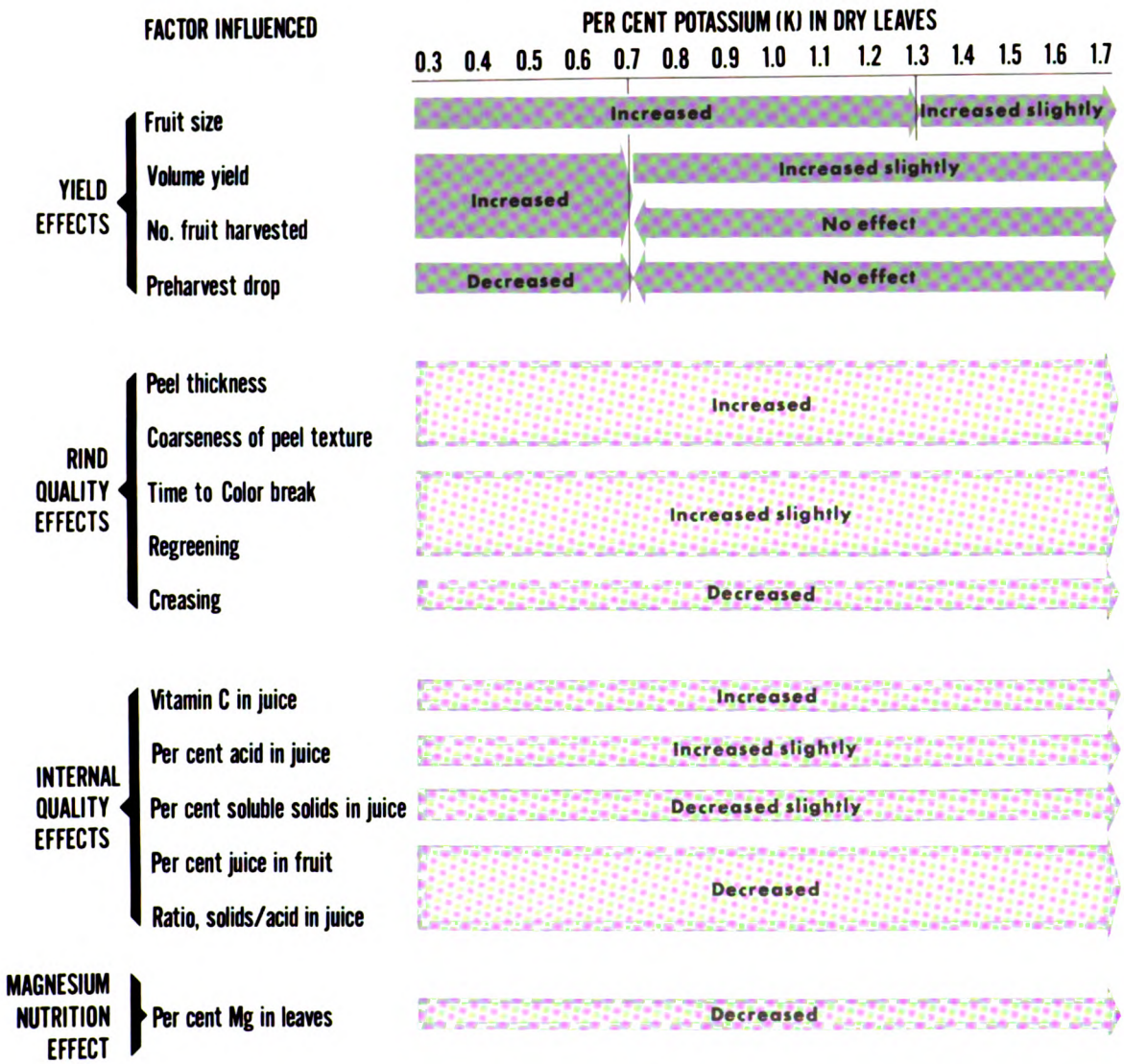

Fig. 6–3. Influence of the percentage of potassium in five- to seven-month-old spring-cycle orange leaves from nonfruiting shoots upon factors of yield, rind quality, internal quality, and magnesium nutrition. (From Embleton, Jones, and Platt, 1967).

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Fruit Quality.—Throughout the range of leaf levels observed in California, elevating the level of potassium in orange trees may have some adverse effects on peel thickness and texture, time to color break, and regreening. Creasing, if present, is usually reduced by elevating the potassium level. Within the fruit, a higher potassium level is associated with a greater concentration of vitamin C and total acid in the juice, and a lower total soluble solids, juice percentage, and ratio of total soluble solids to acid (fig. 6–3).

Similar effects on fruit quality have been observed in Florida (Koo, 1966). Koo also reported that more fruit splitting was associated with low levels of potassium. The maximum concentrations of potassium attainable in leaves is greater in the acid, sandy areas of central Florida than in California. Potassium effects on grapefruit quality are similar to those for the orange.

With the exception of the effects on peel thickness, juice percentage, and possibly peel texture (Embleton and Jones, 1966), responses of lemons to potassium are similar to those of the orange. However, these responses are not of equal economic importance because of the differences in quality standards. In the lemon, an increase in potassium in the tree reduces peel thickness and increases the ratio of length to width of the fruit, juice percentage, concentration of total and ascorbic acid in juice, pounds of acid per ton of fresh fruit, and the time to color break. Possibly peel texture is smoother at higher potassium levels. Increasing leaf potassium in the 0.3 to 0.7 per cent range usually has greater effects on fruit quality factors than increasing it in the 0.7 to 1.7 per cent range. The potassium effect on time from anthesis to color break permits fruit to remain green longer and hence grow larger before harvesting (Embleton and Jones, 1966, 1968; Embleton, Jones, and Page, 1967). To date, no adverse effects of high potassium levels in the tree have been observed on lemon fruit quality.

Nutritional Effects.—One of the commonly-observed reciprocal nutritional effects in citrus is that an increased level of potassium is associated with a reduced level of leaf magnesium. It is not uncommon to observe potassium-induced magnesium deficiency in the field.

Calcium

Calcium deficiency in the field is rare. The diagnostic ranges in table 6–1 were compiled from limited tree growth and yield data from sand- and solution-cultures and field experiments (Anderson and Martin, 1969; Chapman, Joseph, and Rayner, 1965; Spencer and Koo, 1962). The concentration of calcium in leaves may also be used as an indication of the age of leaves. In addition, deficient or excess calcium may indicate a disturbance in the nutrition of some other element.

Magnesium

Nonchlorotic leaves from field experiments provided the evidence for determining the ranges in table 6–1. The ranges are based on yield of fruit. With values in the deficient range, trees generally show moderate to severe foliar deficiency symptoms and moderate to severe twig dieback. In this range, yields are likely to be restricted. With leaf values in the low range, mild foliar symptoms of the deficiency are usually evident, but with little or no twig dieback, and yield usually is not restricted. Leaves with chlorosis from lack of magnesium will generally contain less than 0.08 per cent magnesium.

It appears that magnesium has no effect on fruit quality unless magnesium leaf levels are in the deficient range. Stearns and Sites (1943) showed that magnesium deficiency of oranges and grapefruit in Florida resulted in lower total soluble solids and total acid in the juice. In California, where the defoliation from the deficiency was less severe than in Florida, only lower total soluble solids were associated with the deficiency in Washington navel oranges (Jones, Embleton, and Opitz, 1971).

In the field, values in the high and excess ranges have not been associated with harmful effects other than that such values may indicate a problem in the nutrition of some other element, particularly potassium.

Sulfur

Sulfur deficiency of citrus has not been reported under field conditions. Values in the deficient and low ranges in table 6–1 have been determined from soil-, pot-, and solution-culture studies (Chapman and Brown, 1941; Haas, 1936). Greenhouse experiments have provided information on growth of young trees. The high and excess ranges in table 6–1 are based on greenhouse and field studies (Aldrich, Buchanan, and Bradford, 1955; Haas and Thomas, 1928), and yield associations with sulfur concentrations in leaves in field experiments. Data of Jones *et al.* (1963) and unpublished data of Embleton and Jones

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strongly suggest that yields may be reduced if total sulfur in leaves exceeds 0.40 per cent.

Boron

Sand, solution, and field experiments were the basis for establishing the deficient and low ranges in table 6–1. Values in the deficient range were associated with a loss in both production and fruit quality. The high and excess ranges were established from evidence from sand and solution culture experiments and field observation; leaf symptomatology is the primary point of reference. (Haas, 1945*c;* Kelley and Brown, 1928; Morris, 1938; Roy, 1943; Smith and Reuther, 1949, 1951.)

Iron

The ranges in table 6–1 are based on yield data from one long-term outdoor solution culture experiment with navel oranges (Wallihan *et al.,* 1967) as well as observations in this experiment and others on leaf symptomatology, premature leaf drop, and dieback. Wallihan *et al.* (1967) reported that for fruit production the critical level for iron in the 5- to 7-month-old, spring-cycle leaves from nonfruiting terminals was 30 ppm or slightly above. At this level of iron, chlorophyll concentration in leaves is less than maximum, some premature leaf drop may occur, and slight dieback may develop.

Iron deficiency can be detected visually from the chlorosis pattern, but attempts to make visual diagnosis of iron status may be complicated by other deficiencies or excesses. Simultaneous deficiency of manganese may simply enhance the iron chlorosis pattern.

Iron chlorosis is generally more severe in late winter and spring and occurs predominantly on young growth. As summer approaches, the intensity of chlorosis diminishes and may disappear completely. This chlorosis reduction is associated with an increase in the iron concentration as leaves age. Thus the normal late summer leaf-sampling period may not necessarily be the best time for sampling to determine if there is an iron problem in the tree. Also, all limbs, shoots, and leaves on a tree are not uniformly affected by iron chlorosis under field conditions. For these reasons, a "trouble-shooting" approach—obtaining one sample of green leaves and another of chlorotic leaves, at the time of the year that iron problems are in question—is useful. An estimate of the fraction of each tree affected by iron deficit would provide a useful index of probable loss in fruit production.

It is imperative that leaves be washed in detergent or acid or both, if analytical values are to be valid for iron. Even so, the iron values in table 6–1 are not suitable for interpretation of analytical results obtained from leaves that have been sprayed or dusted with iron-bearing materials. *Iron values in table 6–1 are for use with analytical results from leaves that have not been sprayed or dusted with iron compounds.*

Manganese

Experimental field evidence on yields was the basis of the deficiency range in table 6–1 (Labanauskas and Puffer, 1964). Reductions in yields were not associated with leaf values in the low range. Symptoms of manganese deficiency on young leaves may be observed where leaf levels are in the low range. If the deficiency symptoms persist on spring-cycle leaves that are over five months old, it is likely that a slight loss in yield will occur. Fruit quality effects in the upper part of the deficient range and in the low, optimum, and high ranges have been of little practical consequence, and yield evidence is not even available in the high and excess ranges. Leaf levels in the high and excess ranges are not well defined.

On very acid soils, manganese toxicity can be a problem (Bowman, 1956; Morita and Aoki, 1968; Otsuka, 1964; Yuda, 1970). In these studies, leaf manganese concentrations from 150 to 800 ppm were associated with the toxicity. Aluminum toxicity also appears to be implicated in this problem.

The manganese values in tables 6–1 are not suitable for interpretation of analytical results obtained from leaves that have been sprayed or dusted with manganese-bearing materials. *Manganese values in table 6–1 are for use with analytical results from leaves that have not been sprayed or dusted with manganese compounds.*

Zinc

The deficient range for zinc is based primarily on orange leaf symptomatology. Studies on oranges indicate that yield is not increased by increasing zinc above 16 ppm (Labanauskas, Jones, and Embleton, 1963; Labanauskas and Puffer, 1964). Leaf symptoms of zinc deficiency on oranges generally occur below 16 ppm. With lemons, leaf symptoms of the deficiency may not occur until the zinc level in the leaves drops below 10 ppm; loss in yield from the deficiency may occur with no deficiency symptoms at all (Embleton, Wallihan, and Goodall, 1965). The excess

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range for zinc has been verified under field conditions. Leaf damage and defoliation increased as soil applications of zinc increased zinc level above 300 ppm (Labanauskas, unpublished data). Evidence to date indicates that fruit quality effects are of little practical consequence in the upper part of the deficient range, and in the low, optimum, and high ranges. Severe zinc deficiency resulted in small fruit with very thick peels (Parker, 1937).

The zinc values in table 6–1 are not suitable for interpretation of analytical results obtained from leaves that have been sprayed or dusted with zinc-bearing materials. *Zinc values in table 6–1 are for use with analytical results from leaves that have not been sprayed or dusted with zinc compounds.*

Copper

Although the deficient range for copper is listed as 3.6 ppm, values lower than this have been observed in high producing orchards without deficiency symptoms (Bradford and Harding, 1957). When tree and fruit symptoms of the deficiency occur, yields are likely to be reduced. The values in the high and excess ranges are open to question, as copper can accumulate in roots and cause root damage and yet not be reflected clearly in leaf concentrations (Chapman, Bradford, and Rayner, 1969; Smith, 1956). Thus, leaf levels below 3.6 ppm do not always indicate the presence of the deficiency, but they do indicate that the trees should be closely watched for deficiency symptoms.

The copper values in table 6–1 are not suitable for interpretation of analytical results obtained from leaves that have been sprayed or dusted with copper-bearing materials. *Copper values in table 6–1 are for use with analytical results from leaves that have not been sprayed or dusted with copper compounds.*

Molybdenum

The leaf values in the deficient and low ranges were established from experimental evidence on leaf symptomatology in solution cultures and in the field (Chapman, 1960; Stewart and Leonard, 1953; Vanselow and Datta, 1949). Although the deficient range is indicated at less than 0.06 ppm, it may be considerably less in some cases. Stewart and Leonard (1951) reported that grapefruit leaves from healthy and molybdenum-deficient trees in Florida had molybdenum concentrations below 0.05 ppm in both cases. Chapman (1968) reporting on data from fifty-five commercial orange and lemon orchards, showed that the molybdenum concentration in four- to twelve-month-old spring-cycle leaves from fruiting terminals ranged from 0.02 to 0.04 ppm in a majority of orchards; in seven orchards, however, the concentration was less than 0.02 ppm. Yet no deficiency symptoms were found in any orchard. There is no evidence of the deficiency occurring where the concentration of molybdenum in leaves was above 0.06 ppm. Yield and fruit quality evidence is lacking, except that when heavy leaf drop occurred from the deficiency, the fruit was observed to develop large spots similar to sunburn (Stewart and Leonard, 1953). Apparently molybdenum excess under orchard conditions is of little concern to citrus growth.

Chlorine

Chlorine deficiency has not been reported in the field for citrus. The ranges in table 6–1 are based on leaf symptomatology in sand and solution culture experiments and on field observations. Clear evidence on yield and fruit quality is not available. Yellowing and tip-burn of leaves can occur from root or leaf absorption of chlorine if the concentration in leaves exceeds 0.7 per cent.

Sodium

Sodium deficiency has not been demonstrated in citrus. The ranges in table 6–1 are based on leaf symptomatology in sand and solution culture experiments and in the field. Clear evidence concerning effects of high sodium on yield and fruit quality is not available. There is some evidence that sodium excess could be more adequately diagnosed by root rather than leaf analysis, as an appreciable amount of sodium accumulates in roots before excessive values are found in leaves (Jones *et al.*, 1952).

Lithium

Lithium has not been found to be essential for the growth of higher plants, but its excess can be harmful. Data on association of lithium levels in trees with yield and fruit quality are limited. The ranges in table 6–1 were developed, primarily, from field observations on symptomatology. Early reports, including one on field studies (Aldrich, Vanselow, and Bradford, 1951), indicated that values above about 12 ppm lithium in citrus leaves were in the excess range and could be expected to be associated with symptoms of

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excess in the leaves. Under greenhouse conditions considerably higher concentrations of lithium were associated with toxicity (Bingham, Page, and Bradford, 1964). Hilgeman *et al.* (1970) reported that grapefruit leaves in Arizona with 50 to 60 ppm of lithium in September generally developed excess symptoms in November when the concentrations were 60 to 90 ppm. Vigorous growth and high yields were associated with 24 to 34 ppm in the leaves. They suggest that, for comparative studies, green leaves be gathered in October before necrotic spots begin to develop. They also observed that Washington navel orange, Valencia orange, lemon, and mandarins, growing in areas where grapefruit developed lithium toxicity, did not develop those typical symptoms.

The wide discrepancy in these reports shows that additional research is needed to clarify information on diagnostic levels of lithium in citrus leaves.

Arsenic

Arsenic has not been found to be essential for growth of higher plants, but it is sometimes used on citrus as a pesticide or to hasten maturity of oranges and grapefruit. It occurs in some irrigation waters in sufficient amounts to produce toxic symptoms. Arsenic accumulation is primarily in the roots. However, leaf analysis may be of some value in diagnosing excesses of this element. The levels in table 6–1 are based on leaf symptomatology from field observations. However, in solution culture experiments (Rasmussen and Henry, 1964) growth of Pineapple orange seedlings was reduced at the lowest (0.10 ppm) applied level of arsenic which resulted in 0.4 to 0.5 ppm of arsenic in the leaves and 40 to 50 ppm in the roots. Toxicity symptoms on the leaves occurred at 0.5 ppm of arsenic in the nutrient solution with leaf values of 0.8 to 0.9 ppm and 48 to 96 ppm in the roots. At the higher arsenic rates root damage was extreme and less arsenic accumulated in the leaves. If arsenic toxicity is suspected, it appears that root analysis would be a better diagnostic aid than leaf analysis.

Fluorine

Fluorine is not essential for growth of plants. The values for table 6–1 were taken from Chapman (1960, 1968) and were determined for leaves from fruit bearing shoots. Fluorine injury from atmospheric pollution has been reported from California and Florida (Chapman, 1968).

Other Elements

There are a number of other elements occuring in the earth's crust that are found in citrus leaves such as aluminum, nickel and lead, but, as yet, these have not been associated with problems in the production of the crop. The ranges of concentrations of these elements in the leaves are reported by Chapman (1968).

FACTORS AFFECTING OBSERVED CONCENTRATION OF ELEMENTS IN LEAVES

An understanding of the numerous factors that may affect the concentration of a given element in the leaves should improve sampling procedures, sample handling and preparation, and interpretation of analytical results. There have been a number of studies reflecting on techniques of leaf sampling. These include: Aiyappa, Srivastava, and Muthappa, 1965; Bathurst, 1944; Bouma, 1959, 1961; Bradford, Harding, and Ryan, 1963; Cameron *et al.*, 1952; Chapman, 1960, 1964; Chapman and Brown, 1950; Chapman, Brown, and Rayner, 1947; Chapman, Joseph, and Rayner, 1965; Chapman and Rayner, 1951; Cradock and Wier, 1964; deVilliers and Beyers, 1961; Embleton, Kirkpatrick, and Parker, 1952; Embleton *et al.*, 1963; Finch and McGeorge, 1939, 1945; Harding, Ryan, and Bradford, 1962; Heymann-Herschberg, 1952; Hilgeman, 1941; Hilgeman, Smith, and Draper, 1939; Ismail, Habeeb, and el Wakeel, 1964*a*, 1964*b*; Jones, Bitters, and Finch, 1944; Jones and Parker, 1950, 1951; Jones, Van Horn, and Finch, 1945; Kelly and Cummins, 1920; Koo and Sites, 1956; Koto and Takeshita, 1955, 1956; Labanauskas, Jones, and Embleton, 1959; McGeorge, 1955; Martin, 1939, 1942; Martin-Prével *et al.*, 1965, 1966; Monselise and Heymann-Herschberg, 1953; Nadir, 1965; Ogata, 1968; Oppenheimer, 1945; Reitz and Long, 1952; Reuther and Smith, 1951, 1954; Reuther *et al.*, 1957; Reuther, Smith, and Specht, 1949; Smith, 1966; Smith and Reuther, 1950; Smith, Reuther, and Specht, 1952; Steyn, 1961; and Wallace, Mueller, and Squier, 1952.

Leaf Age

Probably more information is available on the effect of age of leaf on leaf composition than any other factor that should be considered in sampling leaves. Among the studies on this effect are: Cameron *et al.*, 1952; Chapman and Brown, 1950; Chapman *et al.*, 1947; Cradock and Weir, 1964; Embleton *et al.*, 1952; Finch and McGeorge,

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1939, 1945; Heymann-Herschberg, 1952; Hilgeman, 1941; Hilgeman *et al.*, 1939; Ismail *et al.*, 1964*a*, 1964*b*; Jones *et al.*, 1944; Jones and Parker, 1950, 1951; Jones *et al.*, 1945; Kelley and Cummins, 1920; Labanauskas *et al.*, 1959; Martin, 1942; Reuther *et al.*, 1957; Smith, 1966; Smith and Reuther, 1950; Smith *et al.*, 1952.

Leaf age has a large effect on the concentrations of many of the nutrient elements in leaves. Thus, any diagnostic standard must be qualified for leaf age, and that age must be known and controlled if the standard is to be used effectively. Generally, the concentrations of elements change most rapidly during the first month when the leaf is expanding; during the next two or three months, when the leaf is maturing, the rate of change is less. The concentration of most elements is rather stable for the five-to-seven-month age period, making this the period when the concentrations can usually be used to best advantage for diagnostic purposes. Past this age period, the changes for some elements gradually increase in rate.

There is less consistency in the effects of age on the concentration of nitrogen than on concentrations of other elements. Differences in timing of nitrogen applications can change the shape of the seasonal curve for concentration of nitrogen, particularly on sandy soils with low nitrogen reserves (Jones *et al.*, 1944; Smith, 1966). Most published data show that where there are ample nitrogen supplies in soil throughout the year, the concentration in leaves generally decreases with an increase in leaf age. Composite curves showing the effect of age of spring-cycle leaves from nonfruiting terminals on concentrations of a number of elements appear in figures 6–4, 6–5, and 6–6. The concentration of magnesium may increase after six months of age, may remain rather constant, or may decrease as in figure 6–5. The concentrations of phosphorus and potassium decrease, while those of calcium, boron, iron, and manganese increase, and zinc and copper change very little with age.

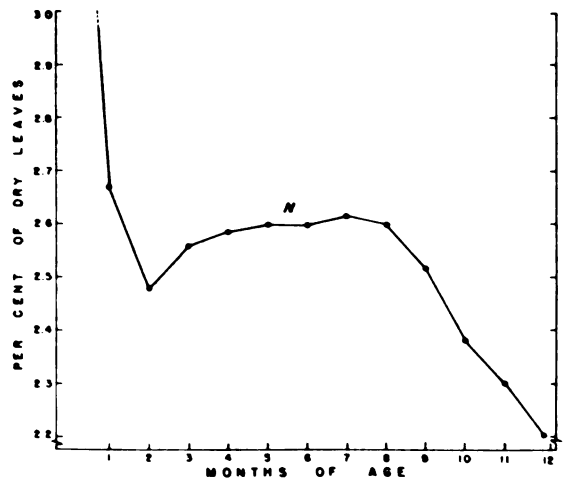

Fig. 6–4. Composite seasonal curve showing influence of age of orange leaves on concentrations of nitrogen in leaves from nonfruiting terminals. (Composited from data of Cameron, *et al.*, 1952; Embleton, Kirkpatrick, and Parker, 1952; Jones and Parker, 1950, 1951; and Smith and Reuther, 1950.)

Leaves from Nonfruiting vs. Fruiting Terminals

That leaves from nonfruiting terminals can differ in composition from leaves of the same age from fruiting terminals is shown in table 6–2. It

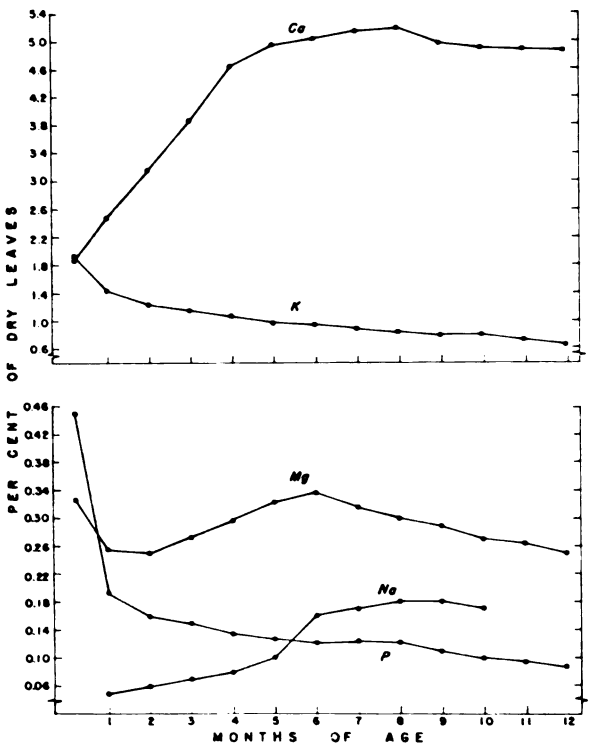

Fig. 6–5. Composite seasonal curve showing influence of age of orange leaves on concentrations of calcium, potassium, magnesium, sodium, and phosphorus in leaves from nonfruiting terminals. (Calcium, potassium, magnesium, and phosphorus composited from data of Cameron *et al.*, 1952; Embleton *et al.*, 1952; Jones and Parker, 1950, 1951; and Smith and Reuther, 1950. Sodium composited from data of Jones and Parker, 1951; and Smith and Reuther, 1950.)

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is obvious from the data that, for many elements, the differences between these two methods of sampling could result in large errors of interpretation if the proper diagnostic table of standards were not used. Findings similar to these were reported by Fölscher and Bruwer (1967), Harding *et al.* (1962), and Martin-Prével *et al.* (1966) for nitrogen, phosphorus, potassium, calcium, and magnesium; Aiyappa *et al.* (1965) for nitrogen, phosphorus, potassium, calcium, manganese, and copper; Ogata (1968) for nitrogen, phosphorus, calcium, magnesium, and manganese; Bradford *et al.* (1963) for zinc, manganese, copper, iron, and boron; Bouma (1959, 1961) for nitrogen and phosphorus; Oppenheimer (1945) for nitrogen; Nadir (1965) for potassium; McGeorge (1955) for phosphorus, potassium, and calcium; Chapman *et al.* (1965) for calcium; Smith (1966) for nitrogen, potassium, calcium, and magnesium; Fudge (1939) for nitrogen and phosphorus. In some cases, no differences or opposite results to those in table 6–2 were found by Chapman and Brown (1950) for potassium; McGeorge (1955) for magnesium, iron, and zinc; Fudge (1939) for potassium and magnesium; Nadir (1965) for nitrogen, phosphorus, and calcium; Aiyappa *et al.* (1965) for calcium, magnesium, zinc, copper, and iron; Smith (1966) for phosphorus, potassium, and magnesium.

Data of Koo and Sites (1956), Embleton *et al.* (1963), and Martin-Prével *et al.* (1966) show that leaves from fruiting shoots are more variable in composition than leaves from nonfruiting shoots.

Since differences between the two sampling methods have been found in numerous experiments, the sampling method should be the same as that used for the development of standards that one uses for interpretation of results of analysis. The diagnostic standards in table 6–1 are for leaves from nonfruiting terminals. Chap-

Table 6–2

EFFECTS OF TYPE OF TERMINAL FROM WHICH VALENCIA ORANGE LEAF WAS OBTAINED ON NUTRIENT CONCENTRATIONS IN THE LEAVES, AUGUST 28–30, 1961*

Type of terminal	Macronutrients (Per Cent)				
	N	P	K	Ca	Mg
Nonfruiting†	2.36	0.128	0.86	3.52	0.250
Fruiting‡	1.53	0.083	0.38	3.92	0.349
Significance§	•••	•••	•••	••	•••
	Micronutrients (Ppm)				
	Zn	Cu	Fe	Mn	B
Nonfruiting†	135	5.1	58	77	65
Fruiting‡	118	2.7	48	74	43
Significance§	••	•••	••	N.S.	•••

* Adapted from Embleton *et al.* (1963).

† Five-month-old terminal leaves from spring-cycle growth.

‡ First five-month-old, spring cycle leaves behind fruit.

§ N.S., indicates that the difference between means is not statistically significant.

•• Indicates that the difference between means is significant at the 1% level.

••• Indicates that the difference between means is significant at the 0.1% level.

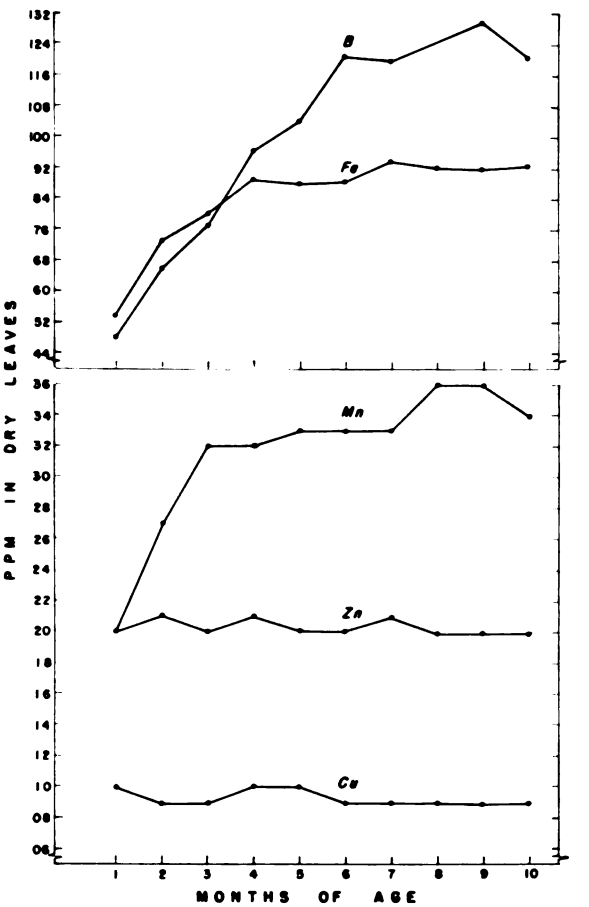

Fig. 6–6. Composite seasonal curve showing influence of age of orange leaves on concentrations of boron, iron, manganese, zinc, and copper in leaves from nonfruiting terminals. (Composite of data from Labanauskas, Jones, and Embleton, 1959; and Smith, Reuther, and Specht, 1952.)

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man (1960) presented standards for leaves from fruiting terminals.

Those that favor selecting leaves from fruit-bearing terminals claim that it is easier for inexperienced personnel to obtain the correct leaf age by this method.

The authors prefer the use of leaves from nonfruiting terminals for the following reasons: (1) they are usually the predominant type of terminal; (2) they can be more rapidly sampled; (3) it is not uncommon that the first and subsequent leaves behind the fruit are older than spring-cycle leaves, and a sampler, with a false sense of security, may not observe this and get older leaves into the sample; (4) they are less subject to temporary changes in mineral composition due to fruit stress; (5) they are the ones most likely to fruit the following season, so one is more interested in their status than in the status of terminals that have already fruited; (6) they have already provided more field evidence relating tree performance to results of leaf analysis; and (7) there are occasions when there is no fruit on the trees, especially when they are young.

Leaves Subtending New Growth

Smith (1966) showed that leaves subtending a new flush of growth had slightly lower concentrations of nitrogen, potassium, and magnesium than the same age leaves from shoots that were not flushing. He sampled at random in respect to the presence or absence of a new flush of growth. The authors prefer to sample entirely from growth that is not flushing to reduce variation attributable to the presence or absence of new growth on shoots sampled.

Position of Leaves on Tree

Koo and Sites (1956) found that the height (0–6, 6–12 feet, and tree tops) from which five-month-old, spring-cycle, Valencia orange leaves were taken had no significant influence on the concentrations of nitrogen, phosphorus, calcium, or magnesium in leaves, but that potassium in leaves from the 0–6 foot height was significantly greater than in leaves from higher positions on the tree. They also found no difference in concentrations of nitrogen, phosphorus, and calcium among five-month-old, spring-cycle leaves from the outside (exposed), canopy (partially-shaded), and inside (shaded) positions on the tree; but potassium was higher in inside leaves and magnesium was lower in canopy leaves. The tree sector from which the leaf is taken (east, south, west, or north) had no significant influence on the concentrations of nitrogen, phosphorus, potassium, calcium or magnesium. In both young and old leaves in Israel, Monselise and Heymann-Herschberg (1953) found slightly lower nitrogen concentrations in leaves from the north sector and inside than in leaves from the north, south, east, or west sectors of trees; phosphorus was slightly lower in leaves from the north sector of the trees. Chapman and Brown (1950) found that three-month-old, spring-cycle, Washington navel orange leaves from fruiting terminals from tree tops (10 to 16 feet from ground) were definitely lower in nitrogen and slightly lower in phosphorus than those from lower positions on the trees; differences in potassium, magnesium, calcium, sulfur, and chlorine were very small. They also found no consistent effect of tree sector on concentrations of nitrogen, phosphorus, potassium, magnesium, sulfur, and chlorine; but calcium concentrations were lower in leaves from the north and east sectors of the trees. Cradock and Weir (1964) in Australia found no significant differences in concentrations of nitrogen and phosphorus between leaves from the northeast sector and samples from all around the trees.

Data of Martin-Prével *et al.* (1965, 1966) on Clementine mandarin and navel orange show that the position from which leaves are taken from the tree can have a significant influence on concentrations of nitrogen, phosphorus, potassium, calcium, and magnesium, although, for the most part, these effects were not consistent from orchard to orchard. However, their data did show reasonable consistency in that leaf phosphorus concentration was greater at higher elevations on the tree than at lower elevations, and leaf calcium was higher in leaves on the south side of the tree than in leaves from the north, east, or west sides.

Data of Koo and Sites (1956) and Embleton *et al.* (1963) indicate that concentrations of most mineral elements vary slightly from basal to tip leaves on a cycle of shoot growth, and that the variation is greater on a fruitbearing shoot than on a nonfruiting shoot.

Large Versus Small Leaves

Chapman and Brown (1950) and Wallace, Mueller, and Squier (1952) reported practically no difference in nutrient composition between large and small leaves. Stevn (1961) reported that large leaves were appreciably lower in potassium than small leaves; differences in nitrogen, phosphorus, calcium, magnesium, sodium, iron, man-

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ganese, zinc, and copper concentration were of little or no practical consequence. Steyn recommended sampling only average size leaves to keep sampling errors to a minimum.

Time of Day

Steyn (1961) showed that leaf composition varied slightly during a given day. Thus, it would be desirable to obtain samples at the same time each day. However, for normal diagnostic purposes this source of variation is not enough to prevent taking samples at any time during the day.

Tree by Tree Variation

In rare instances tree by tree variation for the level of a given element may be so great that a general leaf sample of a block would not reflect the status of many of the trees in the block. For example, in one experiment on lemons where phosphorus and potassium were both deficient and yield increases resulted when these deficiencies were corrected, an initial general leaf sample did not indicate that phosphorus was deficient. However, a subsequent tree by tree leaf sample showed phosphorus levels varying from 0.07 to 0.17 per cent. There was no gradient in phosphorus levels in the block and the high and low phosphorus values occurred more or less at random, presumably because of extreme soil variability. Fortunately, such variation is not common.

Rootstock

Rootstock can have a strong influence on the concentration of elements in leaves as evidenced by the data in Appendix I, table I–1, (p. 488). Data selection in the table were restricted to experiments on budded or grafted trees with various scion varieties. For each element in each experiment, the rootstock effects indicated by the concentrations of elements in the leaves were arranged in an increasing order. The relative concentration rank indicates numerical, but not necessarily statistically significant, differences in concentrations of elements in the leaves.

The data in Appendix I, table I–2 (p. 474), were compiled from the data in Appendix I, table I–1 to give an indication of the consistency of results among the numerous experiments cited. The arrangement of rootstocks in columns 1 and 2 under each element indicates an association with increasingly higher concentrations in the leaves of the element in question. For example, the indications are that trifoliate orange rootstock was generally associated with the lowest and rough lemon rootstock with the highest nitrogen concentration in leaves. For the most part the effects in the table are not attributable to scion variety, climate, soil, irrigation water, or fertilizer, since in each experiment these factors were presumably uniform. However, indirectly, there may be some effect of some of these factors. For example, most of the experiments reported under chlorine in table 6–3 were conducted in the Lower Rio Grande Valley of Texas, and the general results there are not in accord with those of the unpublished California data of Labanauskas *et al.*

Certain interactions reduce the consistency of the overall effects of rootstock *per se* on leaf composition. For example, data of Wallihan and Garber (1968*b*) show that under acid soil conditions sour orange rootstock resulted in a markedly lower concentration of iron in leaves than did sweet orange. When calcium carbonate was added to the soil there was practically no difference between the two stocks. In spite of these interactions and other effects, there is a consistency, under a wide variety of ecological conditions in the effects of rootstock on leaf composition, as shown in Appendix I, table I–1.

Among the rootstock generalizations that appear to be justified by the data in Appendix I, tables I–1 and I–2 (p. 448–87) are the following:

(1) Trifoliate orange, Cleopatra mandarin, and Sampson tangelo rootstocks are associated with a lower nitrogen level in leaves than rough lemon.

(2) Sour orange and rough lemon are associated with less phosphorus in scion leaves than grapefruit or trifoliate orange.

(3) Cleopatra mandarin is conspicuous because of low potassium and high calcium concentrations in associated scion leaves.

(4) Sour orange and Sampson tangelo are also associated with low potassium levels in scion leaves.

(5) Grapefruit is less efficient than Sampson tangelo, Cleopatra mandarin, trifoliate orange, Rusk citrange, and rough lemon in imparting high levels of magnesium in scion leaves.

(6) Alemow, *Severinia buxifolia*, and sour orange result in lower boron concentrations in scion leaves than most other rootstocks.

Wutscher *et al.* (1970) reported, after Appendix I, tables I–1 and I–2 were compiled, on effects of sixteen rootstocks on growth and leaf

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composition of CES No. 3 Redblush grapefruit over a four-year period. Their findings were in reasonably good accord with the relative rankings in Appendix I, table I–2. In addition they showed that within the sixteen rootstocks *Severinia buxifolia* was associated with the lowest boron and magnesium and the highest phosphorus, potassium, zinc, manganese, and copper levels in leaves. Troyer citrange resulted in relatively low phosphorus and potassium and in markedly higher chlorine in leaves. As rootstocks, several new hybrids imparted lower boron leaf levels than sour orange.

These rootstock effects do not detract from the value of leaf analyses as a diagnostic tool. In fact, they show the usefulness of the leaf analysis approach in delineating rootstock effects where other influential factors are not varied. These results indicate that it may be necessary to apply more fertilizer for one rootstock than for another to attain a predetermined level of an element in leaves. These results also show that some rootstocks impart lower leaf levels of potentially toxic elements than other stocks.

Scion

A summary of the effect of scion variety on the concentration of elements in leaves is given in Appendix I, table I–3 (p. 488). There are not enough data in the literature to warrant a table on specific scion effects as was done for rootstocks in Appendix I, table I–2 (p. 474). However, there are some consistent effects that appear in Appendix I, table I–3 (p. 488). The Valencia orange scion was associated with lower concentrations of nitrogen and potassium and a higher concentration of magnesium than was the navel orange scion. Valencia and Hamlin orange scions had a lower concentration of sodium than did the grapefruit scions. Observations by the authors indicate that when other factors are similar grapefruit scion leaves contain less nitrogen than Valencia or navel orange scions.

Distribution of Irrigation Water

Uneven distribution of irrigation water can result in apparent differential leaching of fertilizer distribution patterns in an orchard and thereby affect leaf composition. This is shown in table 6–3. It appears from the data that trees next to the irrigation gate, which received the water first in the flooding process, were getting more water than the trees at the lower end of the border; presumably, more nitrogen was leached from the root zone of the trees near the irrigation gate. Differences in soil structure in various profiles created by land leveling may further aggravate this uneven distribution problem. The difference in leaf nitrogen in table 6–3, created by irrigation management practices, resulted in significant yield differences. Under this irrigation management practice, the differential effects on nitrogen in leaves would have to be considered in delineating sampling units.

Table 6–3
INFLUENCE OF IRRIGATION PRACTICE UPON THE PERCENTAGE OF NITROGEN IN GRAPEFRUIT LEAVES, APRIL, 1964*

Distance from Irrigation Gate (Tree Spaces)	Per Cent N in Dry Leaves†
2–3	2.14$_{y}$‡
4–5	2.15$_{y}$
6–7	2.19$_{y}$
8–9	2.23$_{yz}$
10–11	2.33$_{z}$
12–13	2.30$_{z}$
14–15	2.32$_{z}$

* Data from a nitrogen experiment in a mature grapefruit orchard growing in a sandy soil in the Coachella Valley, California. Trees were irrigated by the border flood system. The total border enclosed seventeen trees in a single row.

† Each value is the mean from three single-tree replications of six differential nitrogen treatments. Six-week-old, spring-cycle leaves from nonfruiting terminals.

‡ Ranked at the 1% level of significance.

In a furrow-irrigated orchard, Jones and Embleton (1956) showed that the concentration of potassium in leaves on trees at the head of the irrigation run had about 0.1 per cent less potassium than those 18 or 30 trees further away. Presumably, this was due to a decrease in the amount of water penetration with an increase in distance from the pipeline.

Yearly Variations

Smith (1966) cites a number of examples of yearly variations in macronutrient concentrations in leaves for which no clear explanation was evident. This simply emphasizes that more sound decisions can be made with several years' leaf analysis data than with only one. In spite of these yearly variations, leaf analysis can be used as a tool to maintain elements in a desirable range. An example of this for nitrogen control is shown in table 6–4. Although significant variations may occur from year to year, these variations are of little practical consequence if they remain within

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or near the optimum range. These variations emphasize the importance of maintaining a year by year record of analyses so that adjustments can be made to maintain the levels in the optimum range. Such a record also shows trends that develop with time and in some cases enables one to anticipate future developments. For example, the authors observed that Valencia oranges planted in a soil with a relatively low potassium supplying capacity, initially had a high level of potassium in leaves. As the trees aged the level decreased gradually, and leaf analysis indicated when potassium needed to be added to the fertilizer program.

Observations by the authors suggest that under arid conditions, particularly where furrow irrigation is used, nitrogen in the soil moves by capillarity to the furrow ridges and to the surface of soil under trees and becomes positionally unavailable to trees. Frequently, following wet winters when considerable water penetrates through the tree canopy, the nitrogen concentration in leaves is found to be higher than in previous years, even though no nitrogen was applied. It appears that rainfall moves the nitrogen that was positionally unavailable into the root zone. Indirect effects of this type may initially cause one to discount the value of leaf analysis, when in reality leaf analysis measures results of an unexpected influential factor.

Applied Elements

Applications of essential fertilizer elements to acid soils generally increase the concentration of the applied element in the leaves. On alkaline soils, application of potassium, calcium, magnesium, iron, manganese, zinc, and copper may be ineffective in increasing the concentration of the applied element in leaves. If needed, they are frequently applied as foliar sprays.

Table 6–4
YEAR-TO-YEAR VARIATIONS IN CONCENTRATIONS OF NITROGEN IN LEAVES FROM MATURE VALENCIA ORANGE TREES WHERE LEAF ANALYSIS WAS USED AS A GUIDE TO NITROGEN FERTILIZATION (APPROXIMATELY 100 ACRES IN 7 UNITS)

Date, N Rate, Percentage of Leaf N*	Sampling Unit						
	1	2	3	4	5	6	7
1961							
lb N/tree	1	1	1	1	1	1	1
% leaf N, Oct.	2.44	2.41	2.46	2.32	2.49	2.44	2.18
1962							
lb N/tree	1	1	1	1.5	1	1	1.5
% leaf N, Sept.	2.44	2.49	2.38	2.58	2.46	2.55	2.52
1963							
lb N/tree	1	1	1	1	1	1	1
% leaf N, Oct.	2.63	2.60	2.66	2.63	2.60	2.49	2.58
1964							
lb N/tree	1	1	1	1	1	1	1
% leaf N, Sept.	2.41	2.49	2.44	2.49	2.55	2.44	2.55
1965							
lb N/tree	1	1	1	1	1	1	1
% leaf N, Oct.	2.46	2.55	2.41	2.49	2.60	2.60	2.49
1966							
lb N/tree	1	1	1	1	0.8	0.8	1
% leaf N, Sept.	2.55	2.60	2.50	2.48	2.70	2.52	2.42
1967							
lb N/tree	1	1	1	1	0.6	1	1
% leaf N, Oct.	2.49	2.55	2.58	2.52	2.49	2.52	2.44
1968							
lb N/tree	1	1	1	1	1	1	1
% leaf N, Oct.	2.52	2.38	2.41	2.46	2.44	2.60	2.55

Source: The authors express appreciation to Mr. A. S. Bradford, owner of the Agua Tibia Ranch, San Diego County, California, and Mr. Ray Easton, manager, Bradford Bros., Inc., Placentia, California, for permission to use these data.

* Five- to seven-month-old, spring-cycle leaves from nonfruiting terminals were sampled each year. The intent was to maintain N in the leaves between 2.40 and 2.60%. The N fertilizer was applied in late winter or early spring.

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The influence of nutritional sprays upon concentrations of certain elements in sprayed leaves is shown in table 6–5. The elevated nitrogen level resulting from urea sprays is not as long-lasting, for example, as the magnesium effects from a single magnesium spray. In the case of magnesium, zinc, and manganese, concentrations can be increased in mature leaves, but very little is translocated to subsequent new growth.

An increase in the level of one element in leaves may increase the concentration of another element (sometimes called synergism) or it may reduce the concentration of another element (sometimes called antagonism). Such effects of importance were discussed in some detail in Chapter V of this volume. A general summary of these effects appears in table 6–6.

The response indicated in the table does not necessarily occur in every situation, but if it does occur, it will generally be in the direction indicated. Such responses are more likely to occur if the element in the first column of the table is initially in the deficient or low range.

Amount of Fruit and Time of Harvest

Studies by Chapman and Brown (1950) and Jones and Parker (1951) indicate that the amount of fruit does not greatly influence the concentrations of elements in orange leaves. However, Fudge (1939) found that concentrations of magnesium in grapefruit leaves of seedy varieties were lower and magnesium deficiency symptoms were more severe in heavy than in light crop years. Smith (1966) showed that the magnesium concentration in Marsh grapefruit leaves was only slightly lower in heavy-crop years, but nitrogen and potassium were considerably lower and calcium considerably higher in heavy-crop years. Koto and Takeshita (1955) reported that fifty-year-old satsuma orange trees with a heavy fruit crop had a lower concentration of potassium and a higher concentration of calcium in leaves than nonfruiting trees; nitrogen and phosphorus concentrations were not different. Data of another study by Koto and Takeshita (1956) show no clear effect of crop load on seasonal curves of nitrogen, phosphorus, potassium, calcium, and magnesium concentrations in satsuma orange leaves. Lewis, Coggins, and Hield (1964) selected "on" and "off" Wilking mandarin trees in a given year and found a lower concentration of nitrogen in leaves of the former than in the latter. Ogata (1968) showed that satsuma orange leaves from trees with a heavy crop had significantly higher contents of nitrogen, calcium, and manganese and lower potassium than leaves from trees with a light crop; phosphorus and magnesium were not different. Sato (1961) reported that the potassium concentration in leaves from four- and five-year-old satsuma orange trees growing in pots was notably higher from trees that had all blooms removed than from trees bearing fruit; the effects on nitrogen and phosphorus concentrations were inconsistent.

Jones and Embleton (1968) observed that the percentage of nitrogen and phosphorus in Valencia orange leaves was lower in "on" years than in "off" years, but that the effects of potassium, calcium, and magnesium were inconsistent. They also observed that within any one year the pounds of fruit produced per tree had no consistent effect on leaf nitrogen concentrations, but, in the "on" years only, the concentrations of phosphorus and potassium were inversely correlated and calcium positively correlated with the pounds of fruit produced per tree. In years when the harvest date did not significantly influence the pounds of fruit produced the following year (thus the crop load was equal), a September or October harvest resulted in lower phosphorus, potassium, and magnesium, and higher calcium concentrations than a May or June harvest.

In Florida, collapse of Murcott citrus trees was associated with low nitrogen and potassium in the trees in the "on" year. The severity of the problem was markedly reduced by increasing the rates of nitrogen and potassium (Stewart, Wheaton, and Reese, 1968).

Although the crop load and harvest date of the crop influence the concentration of some elements in leaves, such effects would normally be reflected in routine annual leaf analyses. Applications of fertilizer materials should be adjusted on the basis of the leaf analysis data to maintain optimum leaf levels in each year.

Obtaining the Sample and Sampling Pattern

Results from a leaf analysis can be no better than the sample upon which they are based. The sample must properly represent the block of trees in question. Trees that are different in some respect from most of the trees in the sampling block should not be sampled. In "trouble shooting," poor trees are often compared with good trees. The orchard should be judged for uniformity. Areas of the orchard that appear to be different in tree size and condition, foliage color and density, fruiting and soil conditions,

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Table 6–5
INFLUENCE OF NUTRITIONAL SPRAYS UPON THE CONCENTRATIONS OF CERTAIN ELEMENTS IN SPRAYED VALENCIA ORANGE LEAVES*

Element	Date Sprayed	Composition of Spray	Date of Leaf Sample	Concentration in Dry Leaves	
				Check	Sprayed
N	February 4	10 lb urea/100 gal.	February 20†	2.22%	2.54%
P	November, February, and May	6.2 lb KH_2PO_4/100 gal.	October‡	0.102%	0.117%
K	March 11	40 lb KNO_3/100 gal.	March 30§	0.34%	0.54%
Mg	December 3	9.6 lb $MgSO_4 \cdot 7H_2O$ + 11.8 lb $Ca(NO_3)_2 \cdot 2H_2O$/ 100 gal.	February‖	0.154%	0.182%
Zn	May	1 lb Zn (from $ZnSO_4$)/ 100 gal.	October ••	14 ppm	72 ppm
Mn	May	1 lb Mn (from $MnSO_4$)/ 100 gal.	October••	13 ppm	58 ppm

* Spring-cycle leaves from nonfruiting terminals.
† Ten-month-old leaves washed in distilled water.
‡ Six-month-old leaves washed in 1% HCl, by volume (v/v) for 1 minute.
§ Eleven-month-old leaves washed in distilled water.
‖ Ten-month-old leaves washed in 1% HCl, v/v for 1 minute.
•• Six-month-old leaves washed in 0.1%, v/v detergent (JOY).

Table 6–6
THE GENERAL EFFECT OF AN INCREASE IN THE CONCENTRATION OF ELEMENTS IN CITRUS LEAVES UPON THE CONCENTRATION OF OTHER ELEMENTS*

Element Increased in Leaves	Direction of Influence from an Increase in Element in First Column†															
	N	P	K	Ca	Mg	S	B	Fe	Mn	Zn	Cu	Mo	Cl	Na	Li	As
N	+	–	–	+‡	+	–	–‡	0	0‡	0‡	0‡	?	?	?	?	?
P	–‡	+	–	+	+‡	?	–‡	0	+	–‡	–	?	?	0	?	?
K	–	0	+	–	–	?	+‡	?	–‡	0	0	?	?	?	?	?
Ca	+	0	–	+	–	?	?	?	?	?	?	?	?	?	?	?
Mg	0	0	–	–	+	?	0	?	+	+	–	?	?	?	?	?
S	–	–	–	+	–	+	?	?	?	?	?	?	?	–	?	?
B	0	–	+	–	–	0	+	?	–	0	0	?	?	?	?	?
Fe	?	–	+	+	?	?	?	+	?	?	?	?	?	?	?	?
Mn	0	0	0‡	0	–	?	0	0	+	0	–	?	?	?	?	?
Zn	0	0	+	–	–	?	0	0	0‡	+	–	?	?	?	?	?
Cu	0	0	+	0	0	?	0	?	–	–	+	?	?	?	?	?
Mo	?	?	?	?	?	?	?	?	?	?	?	+	?	?	?	?
Cl	?	?	?	?	?	?	?	?	?	?	?	?	+	?	?	?
Na	?	?	?	?	?	?	?	?	?	?	?	?	?	+	?	?
Li	?	?	?	?	?	?	?	?	?	?	?	?	?	?	+	?
As	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	+

* Adapted from Chapman (1949) who reported upon the effects of a deficiency of an element upon the concentration of other elements in the leaves, and Smith (1966) who reported for Florida conditions upon the effects of an added element upon the concentration of other elements when no elements were known to be deficient. The present authors adapted the table to include their California findings, including some where deficiencies existed.
† ? = uncertain or unknown response; + = increase in concentration in the leaf; – = decrease in concentration in the leaf; 0 = no consistent effect.
‡ Different response than reported by Smith (1966).

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from these criteria in other areas should be sampled separately. Trees on different rootstocks should be sampled separately. Each variety should be sampled separately. If uniform, five to ten acres can be sampled as a unit. If two years' samplings show several uniformly-fertilized units to be similar in elemental leaf levels, these units could be combined into one sample for each of the next four or five years and then sampled separately again to see if any relative change has occurred. Always resample units separately after a change in rate or grade of fertilizer, or a major change in other cultural practice.

Various recommendations have been made on the manner in which a large block of trees should be sampled (Chapman, 1960; Chapman and Brown, 1950; Jones and Embleton, 1960; Reuther and Smith, 1954; Steyn, 1961). The present authors prefer a "diagonal" or a "U-shaped" pattern for selecting trees from which to obtain leaves from a large block. Do not sample border trees. On walking the pattern, select two leaves per tree from each alternate tree on the left and right of the sampler from two positions about 90° apart on each tree. Thus, four quadrants of the trees will be equally represented in the final sample. A minimum of 50 leaves should be in each sample. Obtain leaves from exposed nonfruiting terminals three to six feet above the ground.

Steyn (1961) showed that greater variation in leaf composition existed in a poor orchard than in a good orchard and that more variation existed for a given element in the leaves when that element was deficient than when it was adequately supplied. Therefore, under such conditions more intensive sampling may be necessary to get a sample that adequately represents the block.

For routine maintenance sampling, select nonchlorotic, uninjured leaves. In the presence of iron deficiency, extreme nitrogen or manganese deficiency, or extreme boron excess, it may not be possible to avoid chlorotic leaves. In "trouble shooting," chlorotic or injured leaves are frequently compared with normal, healthy leaves.

The importance of care in obtaining leaf samples cannot be overemphasized. Those who collect samples must be keen observers and very carefully trained for this job. Lack of appropriate discipline in obtaining samples will result in meaningless analytical results and lead to serious errors of omission and commission in formulation of fertilizer programs.

Sample Handling

Because respiration continues in the leaves until they have been dried, the samples should be transported to the laboratory, washed, and dried without delay. Respiration causes a reduction in the dry weight and if handling is prolonged, unduly high results of analysis may result. If samples are transported in an ice chest they may be placed in clean polyethylene, paper, or porous cloth bags. If an ice chest is not used, samples should be placed in clean paper or porous cloth bags and protected from heat. In any event, they should be placed in a refrigerator for overnight storage, if they cannot be washed and dried the same day of collection.

Leaf-Washing Techniques

In addition to proper sampling, leaf cleaning procedures can have important effects on the observed concentrations of elements in leaves (Jacobson, 1945; Labanauskas, 1966; Labanauskas, Baines, and Stolzy, 1965; Smith, Reuther, and Specht, 1950).

Smith *et al* (1950) showed no significant effect of washing techniques on the concentrations of nitrogen, phosphorus, potassium, calcium, magnesium, manganese, and boron in unsprayed citrus leaves; iron and copper concentrations were affected. They showed that, for leaves that were sprayed with iron, copper, or zinc, washing techniques had a great influence on observed concentrations of these three elements in leaves.

Labanauskas (1966) studied the washing of Valencia orange leaves by the following procedures: no washing; handwashing in aqueous solution of 0.1% (by volume) detergent (JOY) by passing the fingers and thumb over the total surface of the leaf, and then rinsing in deionized water; handwashing in 0.1% detergent, rinsing in deionized water, and then dipping leaves in 3% (by volume) HCl for 2 minutes, and again rinsing in deionized water. The trees from which the samples were obtained were sprayed with zinc and manganese materials in July and spring-cycle leaves from nonfruiting terminals were sampled the following October. Results from this study are shown in table 6–7. These data show no significant effect of these washing techniques on the concentrations of nitrogen, phosphorus, potassium, calcium, and boron. Magnesium in unwashed leaves was slightly higher than in detergent-washed leaves. A slight sodium contamination may be attributed to the detergent wash

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Table 6–7
EFFECTS OF DIFFERENTIAL WASHING TECHNIQUES ON THE CONCENTRATIONS OF MACRO- AND MICRONUTRIENTS IN VALENCIA ORANGE LEAVES

Washing Techniques	Concentrations in Oven-Dried Leaves*											
	(Per cent)							(Ppm)				
	N	P	K	Ca	Mg	Na	Cl	Zn	Mn	Cu	B	Fe
Unwashed	2.53	0.147	1.07	3.97	0.422_y	0.061_x	0.022_x	123_y	182_y	5.6_y	367	186_y
Detergent washed	2.56	0.146	1.08	3.97	0.407_x	0.066_y	0.028_x	68_x	94_x	5.1_x	368	61_x
Detergent-acid washed	2.55	0.147	1.07	3.96	0.416_{xy}	0.065_y	0.064_y	65_x	92_x	5.0_x	369	61_x
Significance	N.S.	N.S.	N.S.	N.S.	••	••	••	••	••	••	N.S.	••
Coefficient of variability (%)	2	4	3	3	5	8	32	10	14	9	3	12

Source: Labanauskas (1966).

* Each value is a mean of 64 individual determinations. Subscript letters x and y after values indicate statistical populations. Mean values are statistically significant only if they do not have a subscript letter in common after values. N.S. indicates that the mean values are not significantly different from each other; •• = F value significant at the 1% level or more.

and a definite chlorine contamination was associated with the acid wash. The detergent wash and the acid-detergent wash were equally effective in removing zinc, manganese, copper, and iron contaminations from the surface of the leaves.

No significant leaching of nutrients was observed from these washing procedures. This is in accord with findings of Bhan, Wallace, and Lunt (1959). The authors are currently using the detergent-wash method as described by Labanauskas (1966) whenever zinc, manganese, copper, or iron are to be determined or when magnesium is to be determined and there is a possibility that magnesium deposits could occur on the surface of the leaves. At the present time, when only nitrogen, phosphorus, potassium, or calcium are to be determined, we are washing leaves in tap water by passing the fingers and thumb over the total leaf surface and rinsing in distilled or deionized water.

Smith *et al.* (1950) expressed doubts about the reliability of using leaves previously sprayed with materials containing iron, copper, or zinc for diagnostic purposes for these elements. However, Embleton *et al.* (1963) and Labanauskas and Puffer (1964) concluded from their data that analysis of zinc- and manganese-sprayed leaves, when properly washed, can contribute worthwhile information and lead to a better understanding of resultant treatment effects. However, values shown in table 6–1 are not applicable to these results.

Drying Procedures

Commonly used methods of drying are empirical. The most accurate method of determining moisture content is by toluene distillation (Tyron, 1950). On drying, water and volatile oils are removed from the sample. The amount of these volatiles removed is influenced by a number of factors including the sample itself, temperature, humidity, air circulation, and drying time. Results from oven-drying are close to those from toluene distillation.

Most researchers use drying temperatures between 50° C and 70° C. In a forced-draft oven the samples approach very close to a constant dry weight in 48 hours. Ovens other than forced-draft are not recommended. For drying, samples may be placed in clean cloth bags, open paper bags, plastic screen baskets, or ventilated metal baskets. When heavy metals are to be determined avoid metal baskets that could contaminate the samples. The authors used expanded aluminum baskets.

Although practical drying procedures are empirical and absolute constant dry weights may not be attainable, errors induced by drying procedures are not great and should be of little practical concern if standardized procedures within the time-temperature limits indicated above are used.

Grinding Procedures

Grinding in some mechanical mills can result in contamination with some metals. Where heavy metals are to be determined in the samples,

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nickel- or chromium-plated mills, or agate mortar and pestle may be employed. If micro-methods of analysis are to be used, samples should be ground to pass a 40-mesh screen. A 20- to 30-mesh fineness is satisfactory for macro-methods.

Sample Storage

Most workers store samples after grinding in covered glass containers and re-dry immediately before weighing for analysis. As a matter of expediency, the present authors store ground samples in glassine-lined paper bags and do not re-dry prior to weighing. Granted, some moisture is taken up by samples stored in this manner, even under our dry climate conditions. However, the practicality of this method outweighs the slight error that is induced by moisture absorption. The standards in table 6–1 (p. 184) were developed, for the most part, from samples stored in glassine-lined paper bags without re-drying before weighing. Under humid climate conditions, greater security against moisture absorption may be necessary.

Analytical Procedures

It is beyond the scope of this chapter to go into analytical procedures. However, certain comments are in order. Any leaf-analysis laboratory should constantly monitor the accuracy of analytical results. This can be done by exchanging samples and comparing results with other laboratories. Another useful procedure is to obtain a large "standard sample" of ground leaf material and include in a systematic manner some samples of this material in each set of unknown samples to be analyzed. If results of analyses of the "standard sample" deviate from previous results from this sample, analytical errors are indicated.

General Considerations

From the foregoing discussion it can be seen that there are many potential sources of error in a leaf analysis program. However, this should not discourage one from using such a program. It is a very effective tool and is being widely used commercially in California with good success. If one is aware of the potential sources of error in such a program and utilizes this knowledge to establish uniform, standardized procedures, nutritional influences can be made to work to good advantage in providing conditions favorable for production of the crop, and in securing efficient use and minimizing pollution effects of fertilizer materials. This tool becomes more valuable as one gains experience in its use, and obtains a backlog of information on the orchards in question.

USE AND INTERPRETATION

In the first section of this chapter is a discussion of the effects of each nutritional element on fruit yield, size, and quality, and on the degree of confidence that can presently be placed upon the diagnostic standards for each element. The second section shows the many factors that have the potential of influencing the level of elements in leaves.

With knowledge of these two sections, one has the background to use and interpret results of leaf analysis intelligently. The initial sample from a block of trees should be subjected to a detailed analysis. In subsequent years only nitrogen and those elements that were in a questionable range in the initial year usually need be determined. However, if a recent change in the fertilizer program, or some other significant change in cultural practice has occurred, a detailed analysis should be continued until the effects of the change on leaf analysis are stabilized. This is because a change in one element may affect another (table 6–6). With a uniform fertilizer program, a detailed analysis should be made every four or five years.

Usually all elements should be maintained in the optimum range. There is some annual variation in nutrient levels. It has been observed, for example, that potassium is sometimes lower in leaves during a heavy crop year. With continued use and experience a program usually can be developed that will maintain the elements in the optimum range every year.

Under some conditions, deviation from the optimum range may be justified. As stated previously, in situations where boron or sulfur or both are too high, it may be necessary to maintain nitrogen above the optimum range. Where creasing continues to be a problem, serious consideration should be given to raising the potassium level in trees above the optimum range. If a particular orchard were below the optimum range in potassium and the fruit were maturing early at a time when this factor results in a definite advantage marketwise, one may want to maintain potassium at a low level even though some yield loss would occur. Also, a somewhat low potassium level might be desirable to offset chronically large

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coarse textured fruit in particular blocks. Such situations emphasize the importance of knowing the specific problems in each orchard and the specific effects of various levels of the elements on the problem in question.

In most cases an elemental level approaching or in the deficient range is a warning that a change is needed in the fertilizer program. Levels of elements approaching or in the excess range indicate that direct adverse effects are likely or indirect adverse effects may occur because of interrelations with other elements. For example, an excessive level of nitrogen may indicate a phosphorus deficiency. A higher-than-normal magnesium level is frequently found with potassium deficiency and, conversely, high potassium is frequently associated with low magnesium.

Should an analysis indicate a sudden, drastic change in a fertilizer program the analysis should be verified by obtaining results from another sample. Sampling and analytical errors are not common, but they do occur.

Leaf analysis is a good practical tool to evaluate the nutritional status of an orchard, but it should not be used blindly. Often its greatest value is to enable the orchardist to definitely rule out faulty mineral nutrition as a causal factor in a problem situation and turn attention to another causal factor. It does not reflect soil salinity problems in an orchard. It is a poor indicator of toxicities from accumulation of copper, sodium, and arsenic in roots. There are infrequent favorable or unfavorable responses that result from the application of a fertilizer that cannot be explained by results of leaf analysis. Hopefully, additional research and experience will clarify these exceptional cases, and further refine this presently useful tool.

LITERATURE CITED

AIYAPPA, K. M., K. C. SRIVASTAVA, and D. P. MUTHAPPA. 1965. The nutritional status of seedling mandarin (*Citrus reticulata* Blanco) leaves in Coorg. Indian Jour. Hort. **22**:231–37.

ALDRICH, D. G., and J. R. BUCHANAN. 1954. Soil phosphorus supply in healthy and phosphorus-deficient citrus orchards in southern California. Proc. Amer. Soc. Hort. Sci. **63**:32–36.

ALDRICH, D. G., J. R. BUCHANAN, and G. R. BRADFORD. 1955. Effect of soil acidification on vegetative growth and leaf composition of lemon trees in pot cultures. Soil Sci. **79**:427–39.

ALDRICH, D. G., A. P. VANSELOW, and G. R. BRADFORD. 1951. Lithium toxicity in citrus. Soil Sci. **71**: 291–95.

ANDERSON, C. A., and F. G. MARTIN. 1969. Effects of soil pH and calcium on the growth and mineral uptake of young citrus trees. Proc. Fla. State Hort. Soc. **82**:7–12.

BATHURST, A. C. 1943. New method for estimating the fertilizer requirements of citrus trees. Farming So. Africa **18**:323–27.

——— 1944. Method of sampling citrus leaves for diagnostic purposes. Farming So. Africa **19**:329–30.

BHAN, K. C., A. WALLACE, and O. R. LUNT. 1959. Some mineral losses from leaves by leaching. Proc. Amer. Soc. Hort. Sci. **73**:289–93.

BINGHAM, F. T., A. L. PAGE, and G. R. BRADFORD. 1964. Tolerance of plants to lithium. Soil Sci. **98**:4–8.

BOUMA, D. 1959. The development of the fruit of the Washington navel orange. Austral. Jour. Agr. Res. **10**:804–17.

——— 1961. The development of cuttings of the Washington navel orange to the stage of fruit set. IV. The effect of different nitrogen and phosphorus levels in fruiting cuttings. Austral. Jour. Agr. Res. **12**:1089–99.

BRADFORD, G. R., and R. B. HARDING. 1957. A survey of microelements in leaves of forty-three high-producing orange orchards in southern California. Proc. Amer. Soc. Hort. Sci. **70**:252–56.

BRADFORD, G. R., R. B. HARDING, and T. M. RYAN. 1963. A comparison of the microelement composition of orange leaves from nonfruiting and fruiting terminals. Proc. Amer. Soc. Hort. Sci. **83**:291–94.

BRYAN, O. C. 1961. Malnutrition symptoms of citrus. State of Fla. Dept. Agr. Bul. **93**: 64 pp.

CALVERT, D. V. 1970. Response of 'Temple' oranges to varying rates of nitrogen, potassium, and magnesium. Proc. Fla. State Hort. Soc. **83**:10–15.

CAMERON, S. H., R. T. MUELLER, A. WALLACE, and E. SARTORI. 1952. Influence of age of leaf, season of growth, and fruit production on the size and inorganic composition of Valencia orange leaves. Proc. Amer. Soc. Hort. Sci. **60**:42–50.

CAMP, A. F. and B. R. FUDGE. 1939. Some symptoms of citrus malnutrition in Florida. Univ. Fla. Agr. Exp. Sta. Bul. **335**:55 pp.

CAPRIO, J. M. 1956. An analysis of the relation between regreening of Valencia oranges and mean monthly temperatures in southern Californa. Proc. Amer. Soc. Hort. Sci. **67**:222–35.

CHAPMAN, H. D. 1949. Citrus leaf analysis. Nutrient deficiencies, excesses and fertilizer requirements of soil indicated by diagnostic aid. Calif. Agr. **3**(11): 10, 12, 14.

——— 1960. Leaf and soil analysis in citrus orchards. Univ. Calif. Div. Agr. Sci. Ext. Serv. Manual. **25**: 53 pp.

——— 1961. The status of present criteria for the diagnosis of nutrient conditions in citrus. *In:* Reuther, W. (ed.)., Plant analysis and fertilizer problems. Pp. 75–106. Amer. Inst. Biol. Sci. Publ. 8, Washington, D.C.

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——— 1964. Foliar sampling for determining the nutrient status of crops. World Crops 16(3):36–46.
——— (ed.). 1966. Diagnostic criteria for plants and soils. Univ. of Calif. Div. of Agr. Sci. Berkeley. 793 pp.
——— 1968. The mineral nutrition of citrus. *In:* Reuther, W., L. D. Batchelor, and H. J. Webber (eds.), The citrus industry, Rev. ed., II:127–289. Univ. Calif. Div. Agr. Sci., Berkeley, Calif.

CHAPMAN, H. D., G. R. BRADFORD, and D. S. RAYNER. 1969. Copper toxicity: effect on orange yields. Calif. Citrog. 54:131, 154–56.

CHAPMAN, H. D., and S. M. BROWN. 1941. The effects of sulfur deficiency on citrus. Hilgardia 14:185–201.
——— 1950. Analysis of orange leaves for diagnosing nutrient status with reference to potassium. Hilgardia 19:501–40.

CHAPMAN, H. D., S. M. BROWN, and D. S. RAYNER. 1947. Effects of potash deficiency and excess on orange trees. Hilgardia 17:619–50.

CHAPMAN, H. D., HARRIETANN JOSEPH, and D. S. RAYNER. 1965. Some effects of calcium deficiency on citrus. Proc. Amer. Soc. Hort. Sci. 86:183–93.

CHAPMAN, H. D., and D. S. RAYNER. 1951. Effect of various maintained levels of phosphate on the growth, yield, composition, and quality of Washington navel oranges. Hilgardia 20:325–58.

COOPER, W. C. 1948. A progress report for 1948 on the Texas citrus rootstock investigation. Proc. Lower Rio Grande Val. Citrus and Veg. Inst. 3:128–54.
——— 1961. Toxicity and accumulation of salts in citrus trees on various rootstocks in Texas. Proc. Fla. State Hort. Soc. 74:95–104.

COOPER, W. C., W. R. COWLEY, and A. V. SHULL. 1952. Selection for salt tolerance of some subtropical fruit plants. Texas Avocado Soc. Yearbook 5:24–36.

COOPER, W. C., and B. S. GORTON. 1952. Toxicity and accumulation of chloride salts in citrus on various rootstocks. Proc. Amer. Soc. Hort. Sci. 59:143–46.

COOPER, W. C., B. S. GORTON, and C. EDWARDS. 1951. Salt tolerance of various citrus rootstocks. Proc. Rio Grande Val. Hort. Inst. 5:46–52.

COOPER, W. C., B. S. GORTON, and E. O. OLSON. 1952. Ionic accumulation in citrus as influenced by rootstock and scion and concentration of salts and boron in the substrate. Plant Physiol. 27:191–203.

COOPER, W. C., and A. PEYNADO. 1959. Chloride and boron tolerance of young-line citrus trees on various rootstocks. Jour. Rio Grande Val. Hort. Soc. 13:89–96.

COOPER, W. C., A. PEYNADO, and E. O. OLSON. 1958. Response of grapefruit on two rootstocks to calcium additions to high-sodium, boron-contaminated, and saline irrigation water. Soil Sci. 86:180–89.

COOPER, W. C., A. PEYNADO, and A. V. SHULL. 1955. Boron accumulation in citrus as influenced by rootstock. Proc. Rio Grande Val. Hort. Inst. 9:86–94.

COOPER, W. C., and A. V. SHULL. 1953. Salt tolerance of and accumulation of sodium and chloride ions in grapefruit on various rootstocks grown in a naturally saline soil. Proc. Rio Grande Val. Hort. Inst. 7:107–17.

CRADOCK, F. W., and R. G. WEIR. 1964. Citrus leaf analysis. Agr. Gaz. N. S. Wales 75:1425–31.

DEVILLIERS, J. I., and C. J. BEYERS. 1961. Leaf analysis as a guide to fertilization in commercial orange growing. *In:* Reuther, W. (ed.), Plant analysis and fertilizer problems. Pp. 107–19. Am. Inst. Biol. Sci. Publ. 8, Washington, D.C.

EATON, F. M., and G. Y. BLAIR. 1935. Accumulation of boron by reciprocally grafted plants. Plant Physiol. 10:411–24.

EMBLETON, T. W., and W. W. JONES. 1966. Effects of potassium on peel thickness and juiciness of lemon fruits. HortScience 1:25–26.
——— 1968. Potassium builds lemon quality. Better Crops with Plant Food 52(1):18–19.

EMBLETON, T. W., W. W. JONES, and C. K. LABANAUSKAS. 1962. Sampling orange leaves—leaf position important. Calif. Citrog. 17:382, 396.

EMBLETON, T. W., W. W. JONES, C. K. LABANAUSKAS, and R. G. PLATT. 1971. Leaf analysis and phosphorus fertilization of oranges. Citrog. 56:101, 124.

EMBLETON, T. W., W. W. JONES, and A. L. PAGE. 1967. Potassium and phosphorus effects on deficient 'Eureka' lemon trees and some salinity problems. Proc. Amer. Soc. Hort. Sci. 91:120–27.

EMBLETON, T. W., W. W. JONES, A. L. PAGE, and R. G. PLATT. 1969. Potassium and California citrus. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. 3:1599–1603. Univ. of Calif., Riverside, Calif.

EMBLETON, T. W., W. W. JONES, and R. G. PLATT. 1967. California oranges. Leaf analysis and potassium fertilization. Calif. Citrog. 52:399–400.
——— 1969. Pointers on winter fertilization of citrus. Citrog. 55:17–18, 28.

EMBLETON, T. W., J. D. KIRKPATRICK, and E. R. PARKER. 1952. Visible response of phosphorus-deficient orange trees to phosphatic fertilizers, and seasonal changes in mineral constituents of leaves. Proc. Amer. Soc. Hort. Sci. 60:55–64.

EMBLETON, T. W., C. K. LABANAUSKAS, and W. P. BITTERS. 1962. The influence of certain rootstocks on the concentration of boron, iron, manganese, and other elements in lemon leaves, and on boron toxicity symptoms. Proc. Amer. Soc. Hort. Sci. 80:285–90.

EMBLETON, T. W., C. K. LABANAUSKAS, W. W. JONES, and C. B. CREE. 1963. Interrelations of leaf sampling methods and nutritional status of orange trees and their influence on the macro- and micronutrient concentrations in orange leaves. Proc. Amer. Soc. Hort. Sci. 82:131–41.

EMBLETON, T. W., E. F. WALLIHAN, and G. E. GOODALL. 1965. Effectiveness of soil vs. foliar applied zinc, and of foliar applied manganese on California lemons. Proc. Amer. Soc. Hort. Sci. 86:253–59.

FINCH, A. H., and W. T. MCGEORGE. 1939. Studies of grapefruit fertilization in Arizona. Proc. Amer. Soc. Hort. Sci. 37:62–67.
——— 1945. Fruiting and physiological responses of Marsh grapefruit trees to fertilization. Ariz. Agr. Exp. Sta. Tech. Bul. 105:429–54.

FÖLSCHER, W. J., and A. A. B. BRUWER. 1967. Nutrient element status of leaves and quality characteristics of Valencia oranges. So. African Jour. Agr. Sci. 10:267–77.

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FUDGE, B. R. 1939. Relation of magnesium deficiency in grapefruit leaves to yield and chemical composition of fruit. Univ. Fla. Agr. Exp. Sta. Bul. **331**:36 pp.

GAAFAR, EL-AMIR ABBAS. 1967. The effect of various rootstocks on growth, cropping, fruit quality, and inorganic nutrients of leaves of three types of Mosambi orange (*Citrus sinensis*, Osbeck) scions and the influence of scions on the chemical composition of roots of the various rootstocks. Ph.D. Thesis. Univ. Poona, India. 603 pp.

GALLO, J. R., SYLVIA MOREIRA, ODY RODRIGUEZ, and C. G. FRAGA, JR. 1960. Influência da variedade e do porta-enxêrto, na composicão mineral das fôlhas de citros. Bragantia **19**:307–18.

GOODALL, D. W. and F. G. GREGORY. 1947. Chemical composition of plants as an index of their nutritional status. Imp. Bur. Hort. & Plantation Crops Tech. Commun. 17. I.A.B. Central Sales Branch, Penglais, Wales. 167 pp.

GORTON, B. S., W. C. COOPER, and A. PEYNADO. 1954. Relation of calcium and potassium accumulation in citrus as influenced by rootstock and salinity of irrigation water. Proc. Amer. Soc. Hort. Sci. **63**:49–52.

HAAS, A. R. C. 1936. Deficiency chloroses in citrus. Soil Sci. **42**:435–43.

——— 1945*a*. Boron content of citrus trees grown on various rootstocks. Soil Sci. **59**:465–79.

——— 1945*b*. Influence of the rootstock on the composition of citrus leaves and rootlets. Soil Sci. **60**:445–61.

——— 1945*c*. Boron in citrus trees. Plant Physiol. **20**: 323–43.

—— 1948. Effect of the rootstock on the composition of citrus trees and fruit. Plant Physiol. **23**:309–30.

HAAS, A. R. C. and E. E. THOMAS. 1928. Effect of sulfate on lemon leaves. Bot. Gaz. **86**:345–54.

HARDING, R. B. 1954. Exchangeable cations in soils of California orange orchards in relation to yield and size of fruit and leaf composition. Soil Sci. **77**:119–27.

HARDING, R. B., T. M. RYAN, and G. R. BRADFORD. 1962. A comparison of the macroelement composition of orange leaves from nonfruiting and fruiting terminals. Proc. Amer. Soc. Hort. Sci. **80**:255–58.

HEYMANN-HERSCHBERG, LOTTE. 1952. Soil and leaf analyses as indicators of fertilizer requirement in Shamouti orange groves. Bul. Res. Coun. Israel. **1**(4): 20–37.

HILGEMAN, R. H. 1941. Nitrogen uptake by grapefruit trees in the Salt River Valley. Proc. Amer. Soc. Hort. Sci. 39:119–24.

HILGEMAN, R. H., W. H. FULLER, L. F. TRUE, G. C. SHARPLES, and P. F. SMITH. 1970. Lithium toxicity in 'Marsh' grapefruit in Arizona. Jour. Amer. Soc. Hort. Sci. **95**:248–51.

HILGEMAN, R. H., J. G. SMITH, and G. E. DRAPER. 1939. A preliminary note on nitrogen assimilation by citrus trees. Proc. Amer. Soc. Hort. Sci. 37:58–61.

HODGSON, R. W. 1967. Horticultural varieties of citrus. *In:* Reuther, W., L. D. Batchelor, and H. J. Webber (eds.). The citrus industry. Rev. ed. **II**:431–591. Univ. Calif. Div. Agr. Sci., Berkeley, Calif.

ISMAIL, Z., H. HABEEB, and A. T. EL WAKEEL. 1964*a* Seasonal trends in nitrogen, phosphorus and potassium composition of orange leaves as influenced by rootstock. Agr. Res. Rev. **42**(1):19–40.

——— 1964*b*. Influence of sampling date on the nitrogen phosphorus and potassium concentrations in orange leaves. Agr. Res. Rev. **42**(1):41–52.

JACOBSON, L. 1945. Iron in the leaves and chloroplasts of some plants in relation to their chlorophyll content. Plant Physiol. **20**:233–45.

JONES, W. W. 1966. Nitrogen. *In:* Chapman, H. D. (ed.). Diagnostic criteria for plants and soils. Chap. 2. pp. 310–23. Univ. Calif. Div. Agr. Sci., Berkeley, Calif.

JONES, W. W., W. P. BITTERS, and A. H. FINCH. 1944. The relation of nitrogen absorption to nitrogen content of fruit and leaves in citrus. Proc. Amer. Soc. Hort. Sci. **45**:1–4.

JONES, W. W., and T. W. EMBLETON. 1956. The relation of potassium to fruit size in oranges. Better Crops with Plant Food. **40**(4):22–25.

——— 1960. Leaf analysis—Nitrogen control program for oranges. Calif. Citrog. **45**:349.

——— 1964. Relation of nitrogen nutrition to lemon production. Calif. Citrog. **49**:267, 276.

——— 1967. Citrus nutrition and the development of fertilizer practices. I. In a semi-arid region. Proc. XVII Intern. Hort. Cong. **3**:185–95.

——— 1968. The influence of amount of fruit and time of harvest on macronutrient concentrations in 'Valencia' orange leaves. Proc. Amer. Soc. Hort. Sci. **92**:191–94.

JONES, W. W., T. W. EMBLETON, S. B. BOSWELL, G. E. GOODALL, and E. L. BARNHART. 1970. Nitrogen rate effects on lemon production, quality and leaf nitrogen. Jour. Amer. Soc. Hort. Sci. **95**:46–49.

JONES, W. W., T. W. EMBLETON, S. B. BOSWELL, M. L. STEINACKER, B. W. LEE, and E. L. BARNHART. 1963. Nitrogen control program for oranges and high sulfate and/or high boron. Calif. Citrog. **48**: 107, 128–29.

JONES, W. W., T. W. EMBLETON, M. J. GARBER, and C. B. CREE. 1967. Creasing of orange fruit. Hilgardia. **38**:231–44.

JONES, W. W., T. W. EMBLETON, and K. W. OPITZ. 1971. Effects of foliar applied Mg on yield, fruit quality and macronutrients of 'Washington' navel orange. Jour. Amer. Soc. Hort. Sci. **96**:68–70.

JONES, W. W., T. W. EMBLETON, and R. G. PLATT. 1968. Leaf analysis and nitrogen fertilization of oranges. Calif. Citrog. **53**:367, 376.

JONES, W. W., J. P. MARTIN, and W. P. BITTERS. 1957. Influence of exchangeable sodium and potassium in the soil on the growth and composition of young lemon trees on different rootstocks. Proc. Amer. Soc. Hort. Sci. **69**:189–96.

JONES, W. W., and E. R. PARKER. 1950. Seasonal variations in mineral composition of orange leaves as influenced by fertilizer practices. Proc. Amer. Soc. Hort. Sci. **55**:92–100.

——— 1951. Seasonal trends in mineral composition of Valencia orange leaves. Proc. Amer. Soc. Hort. Sci. **57**:101–03.

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JONES, W. W., H. E. PEARSON, E. R. PARKER, and M. R. HUBERTY. 1952. Effect of sodium in fertilizer and in irrigation water on concentration in leaf and root tissues of citrus trees. Proc. Amer. Soc. Hort. Sci. **60**:65–70.

JONES, W. W., and P. F. SMITH. 1964. Nutrient deficiencies in citrus. *In:* Sprague, H. B. (ed.). Hunger signs in crops. 3rd ed. Chap. 11. Pp. 359–414. David McKay Co., New York, N.Y.

JONES, W. W., C. W. VAN HORN, and A. H. FINCH. 1945. The influence of nitrogen nutrition of the tree upon the ascorbic acid content and other chemical and physical characteristics of grapefruit. Ariz. Agr. Exp. Sta. Tech. Bul. **106**:456–84.

KELLEY, W. P.. and S. M. BROWN. 1928. Boron in the soils and irrigation waters of southern California and its relation to citrus and walnut culture. Hilgardia **3**:445–58.

KELLEY, W. P., and A. B. CUMMINS. 1920. Composition of normal and mottled citrus leaves. Jour. Agr. Res. **20**:161–91.

KENWORTHY, A. L., and L. MARTIN. 1966. Mineral content of important fruit plants. Chap. 24. *In:* Childers, N. F. (ed.). Temperate to tropical fruit nutrition, 2nd ed. Pp. 813–70. Horticultural Publications, Rutgers Univ., New Brunswick, New Jersey.

KOO, R. C. J. 1966. Potash puts quality into citrus. Better Crops with Plant Food. **50**(4):8–11.

KOO, R. C. J., and J. W. SITES. 1956. Mineral composition of citrus leaves and fruit as associated with position on the tree. Proc. Amer. Soc. Hort. Sci. **68**:245–52.

KOTO, M., and S. TAKESHITA. 1955. Experiment on leaf analysis of Satsuma orange. I. Change of leaf composition caused by different position of tree crown in Satsuma orange. II. Effect of fruit on leaf composition in Satsuma orange. Bul. Hort. Branch, Kanagawa Agr. Exp. Sta. No. 3 [Ninomiya, Kanagawa, Japan] :36–39.

——— 1956. Experiment on leaf analysis of Satsuma orange. No. 2 on seasonal change of leaf composition of mature Satsuma orange trees to alternate fruit habit and on condition of fertilization. Part 1. Hort. Branch Kanagawa Agr. Exp. Sta. No. 4 [Ninomiya, Kanagawa, Japan] :43–52.

LABANAUSKAS, C. K. 1962. Correction of manganese deficiencies in grapefruit trees by foliar sprays in desert areas of southern California. Proc. Amer. Soc. Hort. Sci. **80**:268–73.

——— 1966. Effects of orange leaf-washing techniques on removal of surface contaminants and nutrient losses. Proc. Amer. Soc. Hort. Sci. **89**:201–05.

LABANAUSKAS, C. K., R. C. BAINES, and L. H. STOLZY. 1965. Effects of citrus nematode (*Tylenchulus semipenetrans*) and two levels of water suction on nutrient concentrations in navel orange leaves and roots. Soil Sci. **99**:367–74.

LABANAUSKAS, C. K., W. W. JONES, and T. W. EMBLETON. 1959. Seasonal changes in concentrations of micronutrients (zinc, copper, boron, manganese, and iron) in leaves of Washington navel orange. Proc. Amer. Soc. Hort. Sci. **74**:300–07.

——— 1963. Effects of foliar applications of manganese, zinc, and urea on yield and fruit quality of Valencia oranges, and nutrient concentrations in the leaves, peel, and juice. Proc. Amer. Soc. Hort. Sci. **82**:142–53.

LABANAUSKAS, C. K., and R. E. PUFFER. 1964. Effects of foliar applications of manganese, zinc, and urea on Valencia orange yield and foliage composition. Proc. Amer. Soc. Hort. Sci. **84**:158–64.

LEWIS, L. N., C. W. COGGINS, JR., and H. Z. HIELD. 1964. The effect of biennial bearing and NAA on the carbohydrate and nitrogen composition of Wilking mandarin leaves. Proc. Amer. Soc. Hort. Sci. **84**:147–51.

LEYDEN, R. F. 1963. Chemical composition of grapefruit leaf tissue as influenced by rootstock, variety, cultural practice, fertilizer, and season. Jour. Rio Grande Val. Hort. Soc. **17**:72–79.

LILLELAND, O. and J. G. BROWN. 1937. The potassium nutrition of fruit trees I. Soil analyses. Proc. Amer. Soc. Hort. Sci. **35**:327–34.

LUNDEGÅRDH, H. 1951. Leaf analysis. (English translation by R. L. Mitchell.) Hilger and Watts, Ltd. London, England. 176 pp.

MCCOLLOCH, R. C., F. T. BINGHAM, and D. G. ALDRICH. 1957. Relation of soil potassium and magnesium to the magnesium nutrition of citrus. Soil Sci. Soc. Amer. Proc. **21**:85–88.

MCGEORGE, W. T. 1955. Nutrient status of grapefruit orchards as related to fruit quality. Univ. Ariz. Agr. Exp. St., Rept. No. **120**:19 pp.

MARTIN, W. E. 1939. Some effects of cultural practices upon tree composition, yield and quality of Marsh grapefruit in Arizona. Proc. Amer. Soc. Hort. Sci. **37**:68–75.

——— 1942. Physiological studies of yield, quality, and maturity of Marsh grapefruit in Arizona. Ariz. Agr. Exp. Sta. Tech. Bul. **97**:1–48.

MARTIN-PRÉVEL, P., J. DEL BRASSINNE, P. LOSSOIS, and J. J. LACOEUILHE. 1965. Échantillonnage des agrumes pour le diagnostic foliaire. II. Influence de la position des feuilles sur l'arbre. Fruits. **20**:595–603.

——— 1966. Échantillonnage des agrumes pour le diagnostic foliaire. III. Influence du caractere fructifere ou non fructifere des rameaux, de leur hauteur et de l'ombrage. Fruits. **21**:577–87.

MONSELISE, S. P., and LOTTE HEYMANN-HERSCHBERG. 1953. Influence of exposure and age on dry matter content, area and mineral composition of Shamouti orange leaves. Proc. Amer. Soc. Hort. Sci. **62**:67–74.

MORRIS, A. A. 1938. Some observations on the effects of boron treatment in the control of "hard fruit" in citrus. Jour. Pomol. and Hort. Sci. **16**:167–81.

NADAR, M. 1965. Contribution a la determination d'une fumure rationnelle des agrumes par l'analyse foliaire. Al Awamia **16**:123–47.

OGATA, R. 1968. Studies on manganese deficiency in citrus. IV. Effects of fruiting on the manganese content and other mineral composition of Satsuma orange leaves. Jour. Jap. Soc. Hort. Sci. **37**:109–14.

OPPENHEIMER, H. R. 1945. Leaf analyses of Shamouti oranges. Palestine Jour. Bot. [Rehovot] **5**:86–95.

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PAGE, A. L., T. J. GANJE, T. W. EMBLETON, and W. W. JONES. 1969. Soil factors influencing the correction of potassium deficiencies on citrus in California. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. 3:1605–12. Univ. of Calif., Riverside, Calif.

PEYNADO, A., and R. YOUNG. 1962. Performance of nucellar Red Blush grapefruit trees on 13 kinds of rootstocks irrigated with saline and boron contaminated well water over a 3-year period. Jour. Rio Grande Val. Hort. Soc. 16:52–58.

PRATT, P. F., R. B. HARDING, W. W. JONES, and H. D. CHAPMAN. 1959. Chemical changes in an irrigated soil during 28 years of differential fertilization. Hilgardia 28:381–420.

PRATT, P. F., W. W. JONES, and F. T. BINGHAM. 1957. Magnesium and potassium content of orange leaves in relation to exchangeable magnesium and potassium in the soil at various depths. Proc. Amer. Soc. Hort. Sci. 70:245–51.

PRATT, P. F., W. W. JONES, and H. D. CHAPMAN. 1956. Changes in phosphorus in an irrigated soil during 28 years of differential fertilization. Soil Sci. 82: 295–306.

PRATT, R. M. (ed.). 1958. Florida guide to citrus insects, diseases, and nutritional disorders in color. Univ. Fla. Agr. Exp. Sta., Gainesville. 191 pp.

RASMUSSEN, G. K., and W. H. HENRY. 1964. Effects of arsenic on the growth of pineapple orange seedlings in sand and solution nutrient cultures. Proc. Fla. State Hort. Soc. 77:32–35.

RASMUSSEN, G. K., and P. F. SMITH. 1958. Effects of fertilizer rate, rootstock, and leaf age on the level of sulfur in citrus leaves. Proc. Amer. Soc. Hort. Sci. 71:241–47.

REITZ, H. J., and R. C. J. KOO. 1960. Effect of nitrogen and potassium fertilization on yield, fruit quality, and leaf analysis of Valencia orange. Proc. Amer. Soc. Hort. Sci. 75:244–52.

REITZ, H. J., C. D. LEONARD, I. STEWART, R. C. J. KOO, D. V. CALVERT, C. A. ANDERSON, P. F. SMITH, and G. K. RASMUSSEN. 1954. Recommended fertilizers and nutritional sprays for citrus. Univ. Fla. Agr. Expt. Sta. Bul. 536*b:* 14 pp.

REITZ, H. J., and W. T. LONG. 1952. Mineral composition of citrus leaves from the Indian River area of Florida. Proc. Fla. State Hort. Soc. 65:32–38.

REUTHER, W., T. W. EMBLETON, and W. W. JONES. 1958. Mineral nutrition of tree crops. Ann. Rev. Plant Physiol. 9:175–206.

REUTHER, W., W. W. JONES, T. W. EMBLETON, and C. K. LABANAUSKAS. 1962. Leaf analysis as a guide to orange nutrition. Better Crops with Plant Food. 46(3):44–49. (Plant analysis—a special issue, May-June.)

REUTHER, W., and P. F. SMITH. 1951. Tissue analysis as an aid in evaluating the nutritional status of citrus trees. Proc. Rio Grande Val. Hort. Inst. 5:34–45.

——— 1952. Iron chlorosis in Florida citrus groves in relation to certain soil constituents. Proc. Fla. State Hort. Soc. 65:62–69.

——— 1954. Leaf analysis of citrus. *In:* Childers, N. F. (ed.)., Fruit nutrition. Chap. 7. Pp. 257–94. Horticultural Publications, Rutgers Univ., New Brunswick, New Jersey.

REUTHER, W., P. F. SMITH, G. K. SCUDDER, JR., and G. HRNCIAR. 1957. Responses of Valencia orange trees to timing, rates, and ratios of nitrogen fertilization. Proc. Amer. Soc. Hort. Sci. 70:223–36.

REUTHER, W., P. F. SMITH, and A. W. SPECHT. 1949. A comparison of the mineral compositon of Valencia orange leaves from the major producing areas of the United States. Proc. Fla. State Hort. Soc. 62: 38–45.

ROSSELET, F., S. V. HEFER, K. A. W. HELFF, W. LANGENEGGER and F. H. LE ROUX. 1962. Yield and quality responses of Valencia orange trees to fertilisation. So. African Jour. Agr. Sci. 5:351–7.

ROY, W. R. 1943. Studies of boron deficiency in grapefruit. Proc. Fla. State Hort. Soc. 56:38–43.

SAITO, Y., and S. YAMAMOTO. 1963. The relative influence of two citrus rootstock species, *Poncirus trifoliata* Rafin. and *Citrus junos* Tanaka, upon the composition of the scion leaves. Bul. Fac. Agr. Miyazaki. 9:75–88.

SATŌ, K. 1961. The effects of growth and fruiting on leaf composition of citrus trees. *In:* Reuther, W. (ed.), Plant analysis and fertilizer problems. Pp. 400–08. Amer. Inst. Biol. Sci. Publ. 8, Washington. D.C.

SATŌ, K., M. ISHIHARA, and Y. HASE. 1963. Studies on deficiency of satsuma orange trees. II. On the magnesium deficiency of satsuma trees on junos and trifoliate rootstock. Bul. Hort. Res. Sta., Japan, Ser. A., No. 2 [Hiratsuka, Kanagawa]:29–46.

SHANNON, L. M. 1954. Mineral contents of important fruit plants. *In:* Childers, N. F. (ed.), Fruit nutrition. Chap. 18. Pp. 835–67. Horticultural Publications, Rutgers Univ., New Brunswick, New Jersey.

SHANNON, L. M., and J. ZAPHRIR. 1958. The relative influence of two citrus rootstock species upon plant growth and upon the inorganic composition of the scion. Proc. Amer. Soc. Hort. Sci. 71:257–64.

SHARPLES, G. D., and R. H. HILGEMAN. 1960. Influence of differential nitrogen fertilization on production, trunk growth, fruit size and quality and foliage composition of 'Valencia' orange trees in central Arizona. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. 3:1569–78. Univ. of Calif. Riverside, Calif.

SMITH, P. F. 1956. Effects of high levels of copper, zinc, and manganese on tree growth and fruiting of Valencia orange in sand culture. Proc. Amer. Soc. Hort. Sci. 67:202–09.

——— 1962. Mineral analysis of plant tissues. Ann. Rev. Plant Physiol. 13:81–108.

——— 1966. Leaf analysis of citrus. Chap. 8. *In:* Childers. N. F. (ed.). Temperate to tropical fruit nutrition, 2nd ed. pp. 208–28. Horticultural Publications, Rutgers Univ., New Brunswick, New Jersey.

——— 1967. Nutritional responses of citrus grown in a humid climate. Proc. XVII Intern. Hort. Congr. 3:197–214.

——— 1969. Effects of nitrogen rates and timing of application on Marsh grapefruit in Florida. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. 3:1559–67. Univ. of Calif., Riverside, Calif.

SMITH, P. F., and W. REUTHER. 1949. Observations on boron deficiency in citrus. Proc. Fla. State Hort. Soc. 62:31–37.

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——— 1950. Seasonal changes in Valencia orange trees. I. Changes in leaf dry weight, ash, and macronutrient elements. Proc. Amer. Soc. Hort. Sci. **55**:61–72.

——— 1951. The response of young Valencia orange trees to differential boron supply in sand culture. Plant Physiol. **26**:110–14.

SMITH, P. F., W. REUTHER, and A. W. SPECHT. 1949. The influence of rootstock on the mineral composition of Valencia orange leaves. Plant Physiol. **24**:455–61.

——— 1950. Mineral composition of chlorotic orange leaves and some observations on the relation of sample preparation technique to the interpretation of results. Plant Physiol. **25**:496–506.

——— 1952. Seasonal changes in Valencia orange trees. II. Changes in micro-elements, sodium, and carbohydrates in leaves. Proc. Amer. Soc. Hort. Sci. **59**: 31–35.

SPENCER, W. F., and R. C. J. KOO. 1962. Calcium deficiency in field-grown citrus trees. Proc. Amer. Soc. Hort. Sci. **81**:202–08.

STEARNS, C. R., JR., and J. W. SITES. 1943. Fruit quality studies. Fla. Agr. Exp. Sta. Ann. Rept. **1943**: 207–13.

STEWART, I., and C. D. LEONARD. 1951. Molybdenum deficiency in citrus. Proc. Fla. State Hort. Soc. **64**: 51–53.

——— 1953. Correction of molybdenum deficiency in Florida citrus. Proc. Amer. Soc. Hort. Sci. **62**:111–15.

STEWART, I., T. A. WHEATON, and R. L. REESE. 1968. Collapse of 'Murcott' citrus trees. HortScience **3**:230–31.

STEYN, W. J. A. 1961. The errors involved in the sampling of citrus and pineapple plants for leaf analysis purposes. *In:* Reuther, W. (ed.). Plant analyses and fertilizer problems. Pp. 409–30. Amer. Inst. Biol. Sci., Publ. 8, Washington, D.C.

TYRON, M. 1950. An improved apparatus for determining moisture in rubber by distillation with toluene. Jour. Res. Nat. Bur. Standards **45**(5):362–66.

ULRICH, A. 1948. Plant analysis—methods and interpretation of results. *In:* Kitchen, H. B. (ed.). Diagnostic techniques for soils and crops. Chap. 6. Pp. 157–98. Pub. by Amer. Potash Inst., Washington, D.C.

VANSELOW, A. P., and N. P. DATTA. 1949. Molybdenum deficiency of the citrus plant. Soil Sci. **67**:363–75.

WALLACE, A., R. T. MUELLER, and M. G. SQUIER. 1952. Variability in orange leaves of the same age and collected from a single tree. Proc. Amer. Soc. Hort. Sci. **60**:51–54.

WALLACE, A., C. J. NAUDE, R. T. MUELLER, and Z. I. ZIDAN. 1952. The rootstock-scion influence on the inorganic composition of citrus. Proc. Amer. Hort. Sci. **59**:133–42.

WALLACE, A., C. P. NORTH, and E. FROLICH. 1953. Interactions of rootstock, soil pH, and nitrogen on the growth and mineral composition of small lemon trees in a glass house. Proc. Amer. Soc. Hort. Sci. **62**:75–78.

WALLIHAN, E. F., and M. J. GARBER. 1968*a*. Effect of iron nutrition on root:top ratio. Agron. Jour. **60**: 41–42.

——— 1968*b*. Iron uptake by two citrus rootstock species in relation to soil moisture and $CaCO_3$. Agron. Jour. **60**:50–52.

WALLIHAN, E. F., M. J. GARBER, J. R. HAMMOND, WILMA PRINTY, D. S. RAYNER, and R. G. SHARPLESS. 1967. Iron requirement studies of navel orange trees in solution cultures. Hilgardia **38**:247–64.

WUTSCHER, H. K., and E. O. OLSON. 1970. Leaf nutrient levels, chlorosis, and growth of young grapefruit trees on 16 rootstocks grown on calcareous soil. Jour. Amer. Soc. Hort. Sci. **95**:259–261.

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CHAPTER 7

Pruning and Girdling of Citrus

LOWELL N. LEWIS and C. DEAN McCARTY

PRUNING AND GIRDLING OF TREE fruits and vines are horticultural practices handed down from ancient times. They have in common the objective of manipulating various aspects of vegetative and fruiting behavior. Some of the benefits traditionally attributed to pruning and girdling in the practical culture of citrus have been called into question by field research in the past few decades.

Considerable disagreement exists on the role of pruning of citrus as a cultural practice. The response of citrus to pruning is variable, easily reversed by adverse conditions, and often difficult to predict. During the past decade, hand pruning of citrus trees has decreased in many areas of the world because of high labor costs. Recently, the advent of mechanical toppers and hedgers and other power-operated pruning equipment has led to renewed interest in pruning for shaping trees or improving fruit quality and production in older groves that have declined in vigor. Regardless of the means employed to carry out the operation, however, pruning results are always similar.

Even more controversial is the practice of girdling. Citrus varieties which are shy bearers may require girdling to force the trees to set an acceptable crop. Fruit set of varieties which produce normal yields can be increased by girdling. However, in most test plots where records have been kept, succeeding yields decrease even though girdling is continued, and nongirdled trees eventually outproduce girdled trees. Girdling may be an advantage where an orchard is to be removed and the grower wishes to force a heavier-than-normal fruit set for a year or two before orchard removal.

PRUNING

Reasons for Pruning

Pruning has been looked upon by some as the least necessary of all cultural operations. This viewpoint has a basis in fact, since pruning has been shown to be neither essential for growth nor for fruit production. Consequently, many citrus growers consider pruning to be one of the most easily dispensed with of cultural operations, particularly if economic returns do not justify spending money on nonessentials. In both California and Florida, older orchards grown on fertile, well-drained soils, where good fertilizer, irrigation, and pest-control programs are carried out, have remained in good vigor and production for many years with little or no pruning.

This does not mean pruning is without value. Judicious pruning of orange and grapefruit trees may enhance establishment of a strong, well-balanced framework of scaffold branches capable of supporting large amounts of healthy foliage and fruit during the productive life of the tree. In the case of lemons, such pruning is a necessity (fig. 7–1).

During the early life of a citrus tree, removal of entangled or broken branches to assist the establishment and growth of a mechanically

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strong, well-balanced framework of branches constitutes good management practice. After trees attain maturity, maintenance pruning may be carried out to insure a balance between vegetative vigor and the fruitfulness needed for maximum production of high-quality fruit.

Maintenance pruning may improve light penetration into the tree and increase the set of interior fruit (fig. 7–2). Studies by Sites and Reitz (1949) showed that increased soluble solids content and improved rind color were correlated with increased light intensity. The importance of light for good production has been recognized by workers elsewhere than in the United States. Iwasaki and Nishiura (1952) reported that Washington navel oranges in Japan exhibit high fruit drop under shaded conditions. In Israel, Monselise (1951) demonstrated the importance of full sunlight for maximum yields. On the basis of work with the Clementine mandarin and Marsh grapefruit, Monselise suggested that citrus trees were sciophilous in their vegetative growth, but that maximum fruiting required full sunlight.

As citrus plantings age, vigor and yield, for unknown reasons, sometimes drop to the point where production is unprofitable. Occasionally, pruning is attempted to force the tree to produce new and productive fruitwood. This rejuvenation pruning ranges from moderate thinning of a canopy to complete skeletonization of the tree. Skeletonization consists of removing all foliage and wood smaller than an inch in diameter, leaving only the main scaffold and adjoining branches. Partial renewal of fruit-bearing wood may be brought about also by removing older and weaker branches that no longer serve in the manufacture of food or the bearing of fruit. Removal of such limbs lets more light into the tree, promotes sprouting of new buds, and favors production of new growth. The success of all rejuvenation pruning is variable, depending largely on the extent of tree decline and the quality of other orchard-management practices.

Pruning may be a valuable measure in the treatment of orchards suffering from neglect or injury. Combined with an orderly program of fertilization, irrigation, and pest control, removal of decadent wood will improve top-root balance and assist in the recovery of trees. Growers in Israel found pruning beneficial in restoring trees that were neglected during World War II and the country's war for independence (Oppenheimer, 1950).

In some cases, pruning will help in the treatment of diseases, such as melanose in Florida and brown rot in California. For control of these diseases, treatment with Bordeaux spray is necessary. Pruning to remove dead or dying disease-carrying wood assists in the recovery of trees.

The advantage of pruning to facilitate or-

Fig. 7–1. Large unpruned lemon tree more than 20 feet tall. The result is a tangle of branches producing small, scarred fruit. Insect pest-control and harvest costs may be excessive with trees this size.

Fig. 7–2. Pruning opens the tree to light penetration, stimulating the growth of inside wood. To prevent this growth from being shaded out, occasional thinning of the canopy is required.

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chard-management operations varies from grove to grove. In closely planted groves movement of spray rigs, picking trucks, and tillage or other equipment may be improved by removing the occasional branches that interfere with management operations. Where trees are tightly grown together, hedging may be employed to open up an orchard. Hedging cuts should always be as light as possible in terms of the existing problem. Pruning may benefit spray operations by making it possible to obtain greater coverage. In some instances, limiting tree height may make picking easier and less expensive, particularly with lemons.

Thus pruning in the culture of citrus should be looked upon as a measure that may be helpful under a specific set of circumstances or as part of a well-rounded program of citrus management. Pruning should never be indiscriminate, since removal of more than moderate amounts of healthy foliage seriously delays growth and fruiting of young trees and reduces the yield of mature trees.

The Natural Basis for Pruning

Growth Habit of the Citrus Tree.—Most commercially important citrus varieties are upright in growth habit. Unless this tendency is curbed by pruning, tall columnar trees result. The citron, some of the limes, and the satsuma and Mediterranean mandarins lack the upright growth tendency. The upright tendency also varies with individual trees and varieties and under different environmental conditions.

The upright characteristic of citrus trees is most pronounced in the branches, where dominance of the terminal growing portion is commonly very marked (Reed and Halma, 1919). As long as the branch remains in an upright position, dominance persists and the production of lateral shoots is either scant or lacking. If the weight of fruit and leaves forces the branch into a horizontal position, however, terminal dominance ceases and lateral buds along the upper side of the shoot are released into growth (Halma, 1923). Usually one of the upright lateral shoots grows more vigorously than others, becoming the dominant branch (fig. 7–3). The other laterals become fruiting shoots, dropping to a horizontal position, and the cycle is repeated. The dominant branch may become so vigorous that it reduces growth of that part of the parent shoot farthest from the new shoot's point of origin, thereby accomplishing a natural pruning of the mother branch. Thus, the natural sequence of events in the growth of citrus trees is a constant renewal of growth from above, with consequent supression and forcing downward of older growth. A result of this natural habit as trees age is that the lower and interior portion gradually fills with weak and declining wood, which may become so dense that it must be pruned.

The vigor of growth of dominant shoots, as well as their occurrence, varies greatly with variety and climatic conditions. Age and health of a tree and relative shoot position also influence vigor. Under given conditions, shoot growth is most vigorous in the lemon, followed in order by the Valencia oranges, navel oranges, and the grapefruit. Climatic differences have the greatest influence on vigor of shoot growth. In regions of wide seasonal and daily ranges in temperature, such as occur in the great interior valley and desert areas of California, shoot vigor is most pronounced, much more so than in regions of more equitable coastal climates.

Warm, humid climates such as those encountered in tropical areas, or semitropical areas such as Florida, favor even more vigorous shoot growth.

Growth of upright shoots is related also to the age and vigor of the tree. Upright shoots

Fig. 7–3. Upright-growing branch has bent over and lost its terminal dominance. Lateral buds along the upper side have sprouted, one of which which will become dominant and repeat the cycle.

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are most vigorous in young trees. As the growth tendency of shoots declines with age, so does shoot vigor. In general, the larger the branch on which a shoot occurs, the greater is its vigor. Irrespective of their origin, shoots continue to extend until they reach the sunlight. Once full sunlight is reached, terminal extension stops and branching ensues. The eventual result is production of fruit. Fruit weight tends to bend these branches downward, and production of lateral fruit-bearing shoots then occurs. Thus, the shoot is transformed into a fruitful branch.

Physiology of the Citrus Tree.—In the absence of such deterrent factors as improper irrigation, disease, or ecological problems, the balance in the plant between growth and fruitfulness appears to be primarily dependent upon a relation between carbohydrates and nitrogenous compounds. Kraus and Kraybill (1918) described this balance and related it to four general groups of plants. Plants exhibiting either carbohydrate deficiency or nitrogen starvation are obviously unable to grow or fruit normally. On the other hand, plants with a plentiful supply of nitrogen and high carbon assimilation achieve moderate growth and yet bear heavy crops. This physiological condition often is referred to as optimum fruitfulness. Plants which have sufficient nitrogen available, but which manufacture carbohydrates in moderate amounts, produce vegetative growth at the expense of fruit production. This physiological condition is generally referred to as the vegetative state. The essential difference between the two conditions appears to relate to the level and availability of carbohydrate reserves.

A carbohydrate-nitrogen hypothesis serves to explain many, but not all, of the pruning responses observed in healthy, potentially productive citrus trees. Newly planted trees are vegetative for the first few years, a condition that may be greatly enhanced by high soil fertility and available moisture. As the tree grows and leaf surface increases, carbohydrates accumulate and the physiological condition shifts from one of vegetative growth to optimum fruitfulness. Undoubtedly growth regulators within the plant promote the change from the vegetative to the fruitful stage, but such factors still remain to be investigated and can only be speculated upon.

The pruning of young nonbearing trees has been shown to delay initiation of fruiting, whereas severe pruning of young bearing trees often stops fruiting, with formation of new foliage replacing the production of fruit.

Another stage of citrus tree growth, subject to considerable attention in recent years in California, is that in which the tree appears to have passed its prime, fruit production has begun to decline, and devitalization appears to have occurred generally in the tree. Mendel (1950) described the symptoms of this stage as follows: (1) basipetal drying of the shoot from its growing tip; (2) reduction or absence of sprouting; (3) scant, small, misshapen leaves; and (4) low fruit production or none whatsoever. Mendel studied the physiological and anatomical features characteristic of devitalized trees and compared them with healthy trees.

In the transition zone between what appeared to be healthy tissue and the appearance of necrotic tips characteristic of the devitalized stage, Mendel found that the principal anatomical difference was in phloem tissue. Phloem cells were rounder and had thicker walls in areas next to the transition zone. Physiological differences were noted in respiration, carbohydrate accumulation, and phosphorus concentration. Respiration was about 25 per cent lower in the transitional zone than in healthy tissue. Starch concentration was demonstrated to be unusually high and phosphorus content low in the transitional area.

Starch concentration was shown to diminish both basipetally and centripetally. On an entire-tree basis, starch was usually below normal unless at least half of the leaves on the tree were of normal size. Generally, the devitalized stage in the tree's development is typified by a lack of available carbohydrates. In one case, this lack was caused by an insufficient leaf area, preventing adequate carbohydrate assimilation. In a second case, phosphorus deficiency appeared to have limited the supply of carbohydrate. Phosphorus is essential to the phosphorylation reaction responsible for conversion of starch into a phosphorylated hexose. This is the form sugar must assume before it can be taken into the respiration pathway and yield energy for the growth of the tree. The devitalized stage seems to result in an unfavorable carbohydrate-nitrogen relationship because of a phosphorus deficiency. Such a deficiency is probably not caused by the lack of phosphorus available to the plant, but by some problem within the plant that prevents phosphorus from becoming available in needed areas.

The importance of starch concentration in shoot regeneration after pruning was demonstrated by Mendel in an experiment on the Shamouti orange. Fifty per cent of the pruned

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branches containing starch produced new shoots within two months after pruning, whereas only 20 per cent of the branches lacking starch produced new shoots. After complete vegetative regeneration had occurred, pruning was repeated and the same starch pattern was observed.

Apparently, carbohydrate availability, the level of phosphorus, and the nitrogen-carbohydrate balance are the critical factors in shoot regeneration after pruning. Nevertheless, these may be only an expression of more important mechanisms involving the concentrations and interrelationships of as yet unknown plant-growth-regulating compounds.

Mechanics of Pruning

Pruning the Young Tree.—Citrus trees are commonly cut back or headed in the nursery prior to their removal for field planting. Normal heading heights in California range from 24 to 32 inches and average about 30 inches. All varieties of oranges, lemons, and grapefruit are normally headed in about the same manner. An exception is the satsuma mandarin, often headed at 24 inches because of its slower growth habit.

Two types of heading are common. Trees may be topped in the nursery to form a head or grown as unbranched whips and cut back at the time of digging. The whip system is used more often with younger trees that are planted in the field one year after budding. Older trees also may be cut to a single trunk prior to planting. Cutting trees back in this manner facilitates pest control.

Trees topped in the nursery to form a head should be pruned just before removal. Four or five main branches, well spaced around the top of the tree to provide the greatest structural strength, should be cut back to lengths of 6 to 8 inches. All other limbs should be removed. Such pruning is also required to bring the top into balance with the root system, which is reduced in size during balling. If trees are transplanted with bare roots, a large root system is often left, although the balance between top and root may then become even more critical because of root drying or destruction of fine roots that would otherwise remain intact in the ball.

After transplanting in the field, most citrus trees require no pruning for two or three years, other than removal of buds that sprout from the trunk below the head of the tree. In most cases, wrappers placed around trunks to protect young trees from sunburn will sufficiently shade trunks to prevent such sprouting.

Scaffold branches develop after planting. These branches arise from laterals of the original heading. They do not arise from the main trunk, except where whips are planted. Older pruning theory advocated selecting five or six scaffold branches and training them by pruning to form a strong, well-balanced framework to support fruit-bearing foliage. Such a method is sound in theory, but seldom works under field conditions. Young citrus trees typically produce upright branches which droop, forming laterals, and then droop further to form a skirt around the tree (fig. 7–4). Further upward growth is from branches that sprout from the center of the tree and along the upper sides of bending laterals. As these branches grow upwards, they bend under their own weight, and the process is repeated. Under these circumstances, dominance moves from one branch to another. What might appear to be an excellent choice for a main branch one year may fail to continue growth the next.

Occasionally, a small, weak tree produces a vigorous sucker from a point above the bud union on the main trunk. The sucker then takes over and dominates the tree. Sometimes a strong, fast-growing limb becomes dominant and produces a lopsided or unbalanced tree (fig. 7–5). In such cases, pruning will force the tree into a more-normal growth habit. Small irregularities in young trees should be ignored, since citrus habitually

Fig. 7–4. Natural growth sequence. Upright-growing limbs will bend under their own weight. Further upward growth will be from new shoots along the upper sides of these limbs and from the center of the tree. The skirt is formed by laterals which droop to the ground.

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Fig. 7–5. Lopsided tree caused by a dominant fast-growing limb. Such cases are exceptional, and pruning may be used to force the tree into a more normal growth habit. If left unpruned, the condition usually corrects itself, and the tree assumes a normal shape.

grows in this manner and young trees usually become symmetrical within a few years.

Thus, pruning during the first six years of an orchard's life should be limited to removing an occasional unwanted branch that may interfere with growth of a sturdy framework of scaffold branches. Suitably spaced branches should be left to their own growth pattern. Laterals showing signs of crossing to the center of the tree should be removed, along with branches forming weak crotches that are subject to breakage. If regular or semiannual pruning is carried out, undesirable branches may be removed before they become large. A tree is set back less by regular pruning than if large limbs and large amounts of foliage are removed at infrequent intervals.

During their early years, only minor differences exist in the pruning required for most varieties of oranges and grapefruit. Because of a willowy growth habit, some varieties of tangerines and mandarins need thinning of weak branches to encourage the sturdier growth of those remaining. Since lemon trees are more open and irregular in growth habit, they require more pruning than other varieties of citrus. Lemons tend to produce long spindly shoots that are mechanically weak and easily broken. Such shoots should be shortened by pruning back to laterals. Lemon trees also tend to grow strong horizontal branches in all directions through the center of the tree. Without pruning, these branches would soon fill the interior with a tangle of crisscrossing limbs. Careful and frequent attention to the establishment of a good framework is essential with lemon trees. Neglect of pruning (fig. 7–6) only means that trees will have to be cut more severely at a later time, resulting in a delay and reduction of yield.

Blanchard (1931) showed that lemons come into bearing sooner and yield larger crops if pruning is light. During a six-year experiment, beginning in the third year after planting, Blanchard found that lightly pruned trees produced 4,000 pounds of fruit more per acre each year than heavily pruned trees. Studies by Reed and Halma (1919), Shamel (1919, 1920*a*, 1920*b*, 1925, 1927), and Cameron and Hodgson (1941) also substantiated the fact that yield and tree size consistently remain in inverse proportion to the severity and frequency of pruning.

Pruning the Mature Tree.—The bearing orange or grapefruit tree generally requires little pruning. Most experimental work on citrus pruning has indicated that yield of healthy trees is reduced in proportion to the severity of pruning. There may be some situations where light hand

Fig. 7–6. Long upright shoots produced by lemon tree are thinned and cut back to laterals where needed. Pruning of lemons is needed to insure high-quality fruit production.

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pruning or thinning will prove advantageous with such trees, particularly in facilitating orchard-management operations. Light thinning in the top of a tree to promote the growth of inside fruitwood can be helpful. For pest control and ease of harvesting, it may be desirable to limit tree height, however. If pruning to reduce height is excessive, the advantages are easily outweighed by the loss of fruit-bearing surface.

Light thinning may also be useful when top branches decline as trees grow older. Such thinning will permit the remaining branches to produce healthy fruitwood. Pruning of top branches should not be carried to the point of opening the tree to such an extent that sunburn occurs. Where removal of a limb exposes branches to sunburn, the exposed limbs should be protected by a coat of whitewash. In this type of pruning, usually performed by hand, branches should be cut back to laterals rather than left as stubs. Deadwood should be taken out of the tree, although it is seldom economically feasible to remove every dead twig. Weak, nonproductive wood should be removed from the center of the tree, and vigorous sprouts should be bent over, if possible, to produce fruitwood.

Since the skirt of a tree bears a large proportion of the fruit, little pruning should be done to it other than removal of deadwood and the occasional branch that interferes with movement of orchard equipment. As trees grow larger, pruning may also be necessary to restrict each tree to its area of tree spacing (fig. 7–7), thus preventing interlacing of the tops and a subsequent shading out of the skirts (fig. 7–8).

Fig. 7–7. Mature trees beginning to crowd. Light pruning is advisable to prevent this condition. Loss of skirt foliage results in lower production.

Fig. 7–8. Skirt of a tree that has been shaded out by crowding. Loss in bearing area will result in decreased yield. Pruning to prevent trees from reaching this condition is a good cultural practice.

The effects of hand pruning on full-bearing trees were studied by Shamel and Pomeroy on the Washington navel orange (Shamel, 1919, 1925, 1927, 1929; Shamel and Pomeroy, 1942) and on the Eureka lemon (Shamel, 1920*a*; Shamel and Pomeroy, 1933*a*); by Cameron and Hodgson (1941, 1943) on navels and Valencia oranges, the Eureka lemon, and Marsh grapefruit; and by Reed (1917) and Surr (1919) on the navel orange. All of the results obtained were similar, depending on the nature and amount of pruning. In one experiment, for example, trees were pruned moderately twice and received light intermittent pruning over a period of fifteen years (Shamel, 1927, 1929). The pruned trees showed a 3 per cent reduction in yield as compared with unpruned trees. Reed (1917) and Surr (1919) found that one heavy pruning reduced total yield for four subsequent years by 23 per cent.

There can be no question of the general effect of pruning on healthy citrus. Whether trees

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are young or old, pruning is repressive to growth and fruitfulness almost in direct proportion to severity and frequency of treatment. Pruning may or may not improve fruit size (Shamel, 1919, 1925; Surr, 1919), but the decisive factor appears to be the relationship between the vigor of the trees and the amount of fruit they carry.

Lemon trees, as mentioned earlier, grow more openly and irregularly than other citrus varieties. Throughout its life, a lemon tree requires an annual or semiannual pruning to maintain production of large, high-quality fruit. Left unpruned, lemon trees produce tall, upright branches that bend under the weight of fruit and foliage. These bent branches produce numerous laterals that soon form a tangle of crossing branches which bear small and often-scarred fruit. Regular pruning of unwanted branches and shortening of others to laterals results in the development of a low, spreading tree of compact form from which the fruit is readily harvested. The periodic opening of the tree by pruning also gives rise to interior fruitwood which bears fruit of larger and better quality (fig. 7–9). Moderation is still a key word, however, even with lemons. Blanchard (1930, 1932) showed that heavy pruning of Lisbon lemon trees over a six-year period decreased yields about 22 per cent compared with lightly pruned trees. Pruning does hasten the growth of lemons to picking size (Shamel, 1920*a*). The average time between bloom and commercial picking was nine months for lemons on pruned trees compared with eleven months on unpruned trees.

Skeletonization is a more severe type of hand pruning, principally used in attempts to rejuvenate old and decadent citrus trees. The method involves removal of the entire outer shell of growth and all branches less than an inch in diameter (fig. 7–10).

In Australia, skeletonizing has been found to reduce melanose and black-spot-infected fruit, increasing size and improving the crop (Bowman, 1956). Bowman observed, however, that skeletonizing "throws the trees out of production for two seasons." He also stressed the importance of correcting all possible causes of tree decline before pruning.

Kretchman and Krezdorn (1961) suggested

Fig. 7–9. Severely pruned lemon tree. While such heavy pruning represses fruit production, opening of the tree favors the growth of new fruitwood, and lowering tree height favors compactness and facilitates harvesting and pest control.

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that skeletonization offered considerable promise for tree rejuvenation in Florida. They pointed out, however, that the cost of such pruning is high and fruit production is lost the first year after pruning.

A study of Washington navel and Valencia orange trees in California (Lewis, McCarty, and Moore, 1963) indicated that skeletonization was of no commercial advantage to growers in that state (tables 7–1 and 7–2). As reported elsewhere, production was lost for the first year after pruning. This loss proved to be greater than could be compensated for in subsequent years. Fruit size was generally improved, but not sufficiently to overcome losses from decreased yields. The four-year average production of skeletonized trees was 0.70 box per tree less than the unpruned trees for Washington navels and 0.60 box less for Valencias. The importance of good vigor for regrowth after pruning was noted in the study of skeletonized trees. One group of low vigor trees continued to decline after skeletonization, whereas a group of vigorous trees made substantial regrowth.

Thus, skeletonization appears to be of questionable value in the rejuvenation of citrus trees. A grower must be able to withstand a total crop loss for one year, and his labor must be relatively cheap to perform the operation. If his trees are low in vigor because of improper irrigation, poor fertilization, nematodes, or other problems, there may be no improvement in tree vigor or fruit production.

Mechanical Pruning

Development of the mechanical hedger by D. S. Prosser, Jr. (1953) in Florida and the intro-

Table 7–1
COMPARISON OF AVERAGE FRUIT SIZE ON SKELETONIZED (S) AND CONTROL (C) TREES IN CALIFORNIA

Year After Pruning	Fruit Diameter in Inches*													
	Washington Navel								Valencia					
	Plot 1		Plot 2		Plot 3		Plot 4		Plot 5		Plot 6		Plot 7	
	S	C	S	C	S	C	S	C	S	C	S	C	S	C
2nd	2.67	2.55	2.85	2.90	2.90	2.66	2.76	2.70	2.72	2.37	2.68	2.56	2.74	2.41
3rd	2.54	2.47	2.89	2.89	2.74	2.67	2.94	2.31	2.59	2.50	2.70	2.38	2.39	2.35
4th	2.44	2.39	....	....	2.95	2.71	2.60	2.57	2.49	2.36	2.44	2.27	2.52	2.47
5th	....	....	....	....	2.74	2.67	....	....	2.42	2.66	....	....	....	....
6th	....	....	2.66	2.57	2.72	2.66	....	....	....	....	....	....	....	....
Average†	2.55	2.47	2.81	2.75	2.77	2.65	2.77	2.51	2.56	2.50	2.65	2.39	2.55	2.41

* Figure given for each plot is average size for all replications (see table 7–2) in each plot.
† The grand average fruit diameter for all plots was 2.67 inches for skeletonized and 2.53 inches for control plots.

Table 7–2
COMPARISON OF YIELD FROM SKELETONIZED (S) AND CONTROL (C) TREES IN CALIFORNIA

Year After Pruning	Field Boxes per Tree†													
	Washington Navel								Valencia					
	Plot 1		Plot 2		Plot 3		Plot 4		Plot 5		Plot 6		Plot 7	
	S	C	S	C	S	C	S	C	S	C	S	C	S	C
1st	....	0.76	....	8.10	....	6.50	....	4.48	....	4.22	....	7.20	....	5.04
2nd	2.70	3.07	7.10	8.83	4.30	6.50	1.35	0.98	3.75*	7.50	8.30	5.00	2.86*	6.65
3rd	3.18*	4.33	7.89	7.63	5.50	6.75	4.42	4.14	2.45	2.28	8.60	8.80	3.69*	2.78
4th	1.93	2.88	5.25	6.25	4.90	5.30	3.41	3.84	2.33	2.70	6.80	6.80	3.62*	5.54
5th	1.88	1.80	4.39	4.75	7.00	7.30	....	....	4.56	4.38	8.30	8.30	....	....
6th	0.20*	0.70	9.50	12.75	4.30	4.50	....	....	....	....	....	....	....	....
Average‡	1.64*	2.26	5.69	8.05	4.33*	6.14	2.30	3.36	2.62	4.22	6.40	7.22	2.54	5.00

* Values significantly different from the controls at the 95 per cent confidence level.
† Figure given for each plot is average yield per tree.
‡ The grand average yield for all plots was 3.64 boxes for skeletonized and 5.17 boxes for control trees.

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Fig. 7–10. Skeletonized grapefruit tree. All foliage and branches smaller than approximately one inch in diameter have been removed. Cut brush is placed back in the tree to help prevent sunburn.

duction of mechanical topping by P. W. Moore (1958) in California revolutionized pruning methods in citrus culture. This has been particularly true for older orchards where trees have grown together and skirts have been lost from excessive shading.

Hedging.—Hedging consists of cutting trees back vertically on both sides of the row so that the row middle is opened to a predetermined width (fig. 7–11). Such an operation accomplishes several objectives. If trees are just beginning to crowd, light hedging removes enough higher growth to prevent shading of lower skirt foliage and subsequent losses in production. If trees are badly grown together, hedging opens up the orchard, removes dead and decadent wood, and sometimes permits a tree to grow a new skirt. The grove is also opened for passage of equipment used in spraying and other orchard maintenance. A more efficient coverage of insecticidal sprays is made possible, and harvesting of fruit may be accomplished more readily.

Since World War II, closer tree spacing has been the rule in California orchards. As trees reach maturity, pruning becomes necessary to prevent shading out of the lower parts of the trees, leaving only a fruit-bearing canopy. The use of hedgers offers a quick and economical means of keeping closely planted trees from becoming unmanageable (fig. 7–12).

Hedging leaves numerous exposed stubs along the sides of trees. Numerous axillary buds sprout behind these cuts and produce a new wall of foliage. Depending on the amount of wood and foliage removed, fruit yields are usually reduced the year after hedging. Total yields for three or four years after pruning are not reduced nor consistently improved by hedging, according to California data on oranges (table 7–3) and Florida data on grapefruit (Kretchman and Jutras, 1963). Tangerines and lemons in California respond similarly to hedging.

Improved pack-out or grade from hedged orchards has been reported by Moore (1957) and Lee (1962) for oranges and by Kretchman and Jutras (1962) for grapefruit. The authors have observed a slight increase in the quality of fruit on hedged trees, but no significant improvement in yield. A grower who needs to hedge to facilitate

Fig. 7–11. Light hedging removes only the shoots protruding into the alley. A full wall of fruit-bearing foliage remains.

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management operations or because of a crowded grove, however, can probably do so without much loss in production.

Topping.—Topping machines (fig. 7–13) remove the tops of decadent orange and grapefruit trees, thereby channeling light into the tree and stimulating growth of new fruitwood. In the lemon industry, topping is employed to regulate tree height, which is usually determined by the economics and convenience of picking. Mechanical topping or hedging of citrus trees results in the heading back of limbs and a subsequent "rooster tail" type of regrowth as numerous axillary buds sprout around the cut stubs. Such growth necessitates an occasional hand pruning, particularly with lemons.

Table 7–3 presents the results of some topping experiments in California which suggest that the practice decreases the yield of Valencia and navel oranges. Subsequent experiments in California confirmed such effects on yield and also indicated that there is no improvement in fruit quality as a result of topping. Numerous observations in California indicate that when pruning reduces yield, there is also a reduction in the amount of small fruit but no increase in the amount of large fruit.

In contrast to studies in California, Kretchman and Jutras (1962) found that grapefruit in Florida provided the largest returns to growers when trees were hedged on four sides and topped. Returns were lowest for unpruned control trees. Trees that were only hedged provided intermediate returns to the grower.

Table 7–3
AVERAGE ORANGE PRODUCTION PER TREE FOR FOUR YEARS AFTER PRUNING*

Method of Pruning	Citrus Variety	Yield† (boxes)	
		Control Trees	Pruned Trees
Topping	Valencia	1.98	1.92
Topping	Valencia	5.00	4.54
Topping	Navel	5.03	4.32
Topping	Navel	2.92	3.14
Topping	Navel	2.65	2.64
Hedged 2 sides	Valencia	7.10	7.28
Hedged 2 sides	Navel	5.70	5.90
Hedged 2 sides	Navel	6.60	7.90
Hedged 4 sides	Valencia	7.21	6.95
Hedged 4 sides	Valencia	4.37	5.57
Hedged 4 sides	Valencia	11.57	12.20

* Data collected from various California orange groves.
† Values not statistically analyzed; however, differences less than 0.25 box should be considered as equalities.

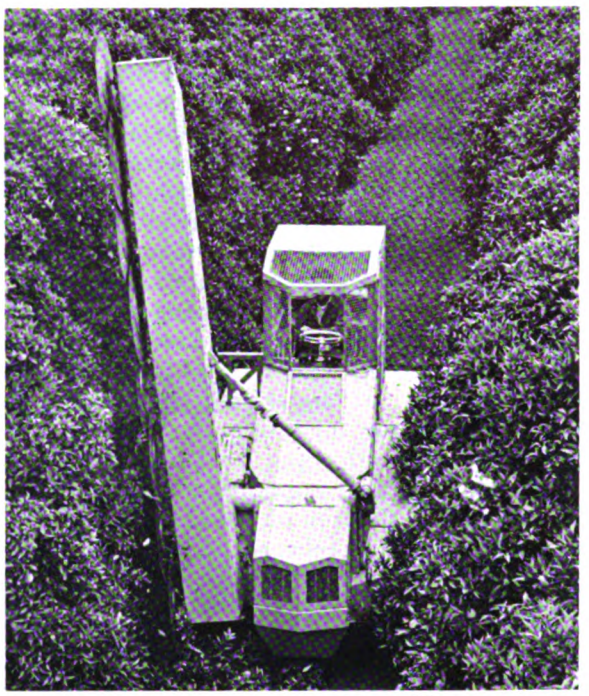

Fig. 7–12. Mechanical hedger used in California orchards. Vertical boom is lowered for movement on highways. (Photo courtesy of Kimball Toppers.)

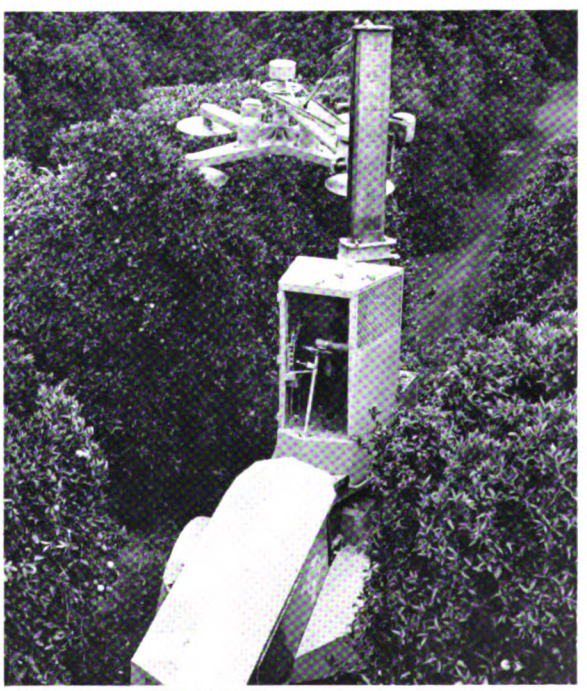

Fig. 7–13. "Whirly-bird" topper. Circular saws on the ends of rotating arms remove top growth. (Photo courtesy of Kimball Toppers.)

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Apparently, light mechanical pruning of citrus does not decrease yields as persistently as hand pruning. Perhaps the tendency to do too good a job of hand pruning results in the removal of too much healthy, fruiting wood. If there are any benefits in dollars returned to the grower, they seem to be based not on yield but on improvement of fruit quality. As in other types of pruning, improved tree vigor is dependent upon correction of the conditions that caused decline.

Much still remains to be learned about mechanical pruning. As yet unknown problems may be associated with the operation. For example, Moore (1957) and the present authors have observed that frost injury is more severe to trees which have recently been mechanically hedged and topped than to unpruned control trees. In all probability, the fruit on pruned trees lacked a protective cover of foliage and was exposed to greater radiation, lowering fruit temperature below that of unexposed fruit.

Pruning Equipment

Tools employed in hand pruning are simple. Equipment consists of a good pair of long-handled loppers, a pair of strong hand shears, a pruning saw, gloves, and a ladder. A pull saw with a folding blade 12 to 18 inches long and a curved cutting edge is most commonly employed. There are several saws of this type on the market. The curve of the cutting edge should not be too great. The form and set of the teeth must be such as to clear the cut of sawdust readily.

Hand pruning has been facilitated by the introduction of air and electric hand tools (Krezdorn, Jutras, and Kretchman, 1961). Both air-operated and electrically operated equipment (fig. 7–14) have specific advantages. Although equipment costs are about the same, the electric generator is less expensive to operate than an air compressor of comparable power. Electric equipment is heavier than hand equipment, however, and requires more maintenance because of drive shafts and gear heads. The air saw has less torque than electrical units and is susceptible to clogging of its bearings and air lines by dirt.

The closest thing to automated pruning is the use of mechanical hedgers, toppers, and brush shredders.

Hedging machines consist of a row of power-driven circular saws on a vertical boom mounted on a self-propelled or tractor-drawn chassis. Such equipment is capable of moving rapidly through an orchard, considerably reducing the time required for a similar job of hand pruning. Topping machines consist of a horizontal arm of circular saws or a sickle-bar mower if lighter wood is to be cut.

Mechanical hedgers and toppers usually are custom-built by commercial operators who contract to hedge and top trees for growers on a per-acre basis. Only large ranches can afford to build and maintain these machines. For the small grower who wishes to do his own pruning, power saws and clippers operated by compressed air or electricity are available. The speed and efficiency of these tools may be increased by using them in conjunction with a mobile platform that makes it possible to position the pruner in the tree. Several companies market specialized machines that can be operated by one man. In some cases, growers

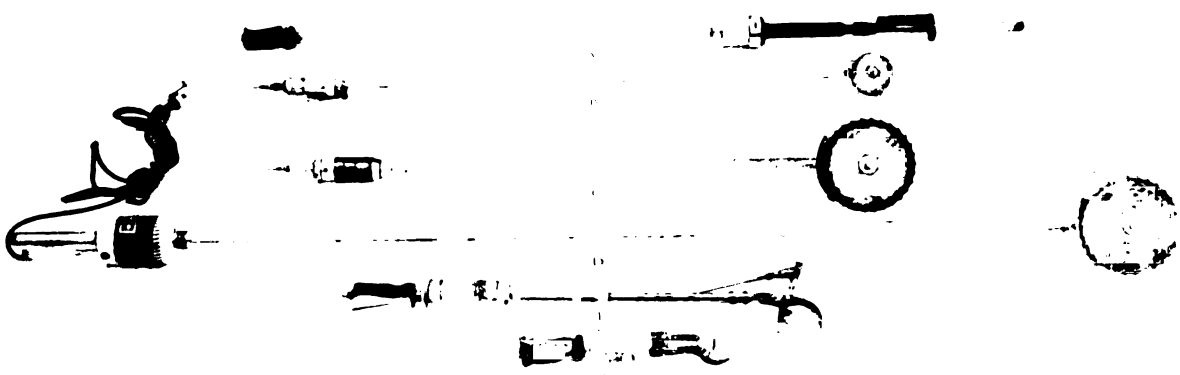

Fig. 7–14. Electric and pneumatic saws and clippers. Use of such equipment is becoming increasingly popular.

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build and mount their own pruning platforms on a tractor or other suitable vehicle which can move through the orchard (fig. 7–15).

After pruning, brush is often gathered into a windrow and shredded with a brush cutter or chipper. The finely cut particles may then be left in the orchard as a mulch.

Protecting the Pruned Tree

Less attention is given to the protection of pruning wounds than in the past. Wounds made by pruning permit the entrance of decay-producing organisms under favorable conditions, but experience has shown that such problems are rare, particularly in dry climates. In addition, the advent of mechanical pruning, which leaves numerous cut stubs, has made treatment of wounds impractical. If a grower wishes to treat large wounds, he may do so by painting them with water-asphalt emulsion. Whitewash, Bordeaux paste, lead paints, varnishes, and shellacs are unsatisfactory for cut surfaces, since they soon dry, crack, and lose their protective qualities. Materials used should not contain solvents that might penetrate and kill the cambium, thus preventing callous formation.

Bark on limbs grown in the shade is extremely susceptible to sunburn. A few hours of exposure to hot sun may cause considerable bark injury. In some cases, growers have found it practical, particularly when trees are topped, to treat exposed portions of limbs with whitewash. Treatment of branches other than those exposed to sunlight is unnecessary and may be detrimental since whitewash provides an excellent habitat for red spider. If only a few trees are treated, whitewash may be applied with a brush. If large numbers are treated, a more practical application method is by means of a power sprayer.

Time of Pruning

Although grower convenience usually dictates the time of pruning, especially in California, studies by Cameron and Hodgson (1943) indicated that best results are obtained if pruning is carried out early in the spring after danger of frost has passed and before trees start a new growth cycle. The rate of top regeneration is most rapid in trees pruned in late spring and early summer, and least rapid in trees pruned in the fall. Late summer or early fall pruning also is undesirable because it produces a late flush that is more susceptible to frost injury the following winter.

Presence of mature fruit on trees may restrict the time of pruning. Navel oranges and winter grapefruit, which are harvested before spring, present little problem. With Valencia oranges and summer grapefruit, both young and mature fruit are on the trees during the spring. Growers therefore prefer to prune these trees when there is the least loss of salable fruit, usually in the late summer. If a grower plans to prune such an orchard, he may find it advantageous to harvest the fruit as early as possible and then proceed with pruning. With some species, the grower may take advantage of an alternate-bearing tendency and prune during the light crop year.

Pruning should not be performed too soon after a freeze. Injury ordinarily becomes visible within a few days on foliage and young growth,

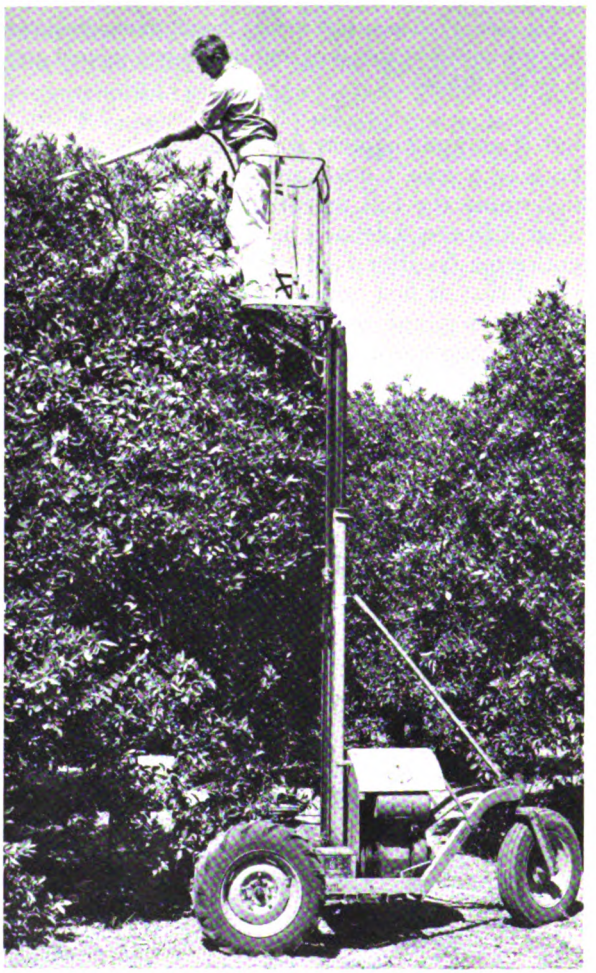

Fig. 7–15. Self-propelled platforms and the use of electric or pneumatic saws greatly increase the efficiency of hand pruning.

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Fig. 7–16. Frost-injured Valencia tree. Pruning should be delayed until new growth is well started and injured area is clearly defined.

Fig. 7–17. Same tree nineteen months after frost injury. Only the smallest branch tips were killed and the tree completely recovered.

but it may not appear for many weeks on older parts of a tree. Consequently, it is impossible to determine the full extent of injury immediately after a freeze. Dieback may continue during the entire season after a severe freeze. In some cases, wood that at first appears to be severely injured and in need of pruning will recover. Pruning should therefore be postponed for six months to a year after damage, permitting time for new growth to take place and for dieback to cease, thus clearly defining the extent of damage (Johnston, 1963). Webber (1919) also found that if frost-injured trees are not pruned until regrowth is well under way, recovery is more rapid than if trees are pruned immediately after injury (fig. 7–16).

No pruning is required where cold injury consists of damage to foliage and small twigs. If a large part of the top of a tree is killed but trunk and scaffold limbs show little damage, the extent of injury cannot be determined for several months. No pruning should be performed until the damage can be evaluated. When pruning is carried out, injured limbs should be cut back below all serious bark injury to the point where vigorous new sprouts are growing. Formation of new framework branches may be aided by further light pruning.

In cases of severe damage, where the entire top of a tree is killed and injury extends to the trunk, a new head must be developed. The old trunk and top should be removed immediately after the extent of damage is determined. The new tree which forms under these conditions will usually have a multiple-trunk system. Experience has shown that this is not objectionable. Immediately after the freeze and up until a new head is well formed, all sprouts should be permitted to grow, thereby bringing the top and root system back into balance. Once this occurs, new growth should be pruned out so that several new shoots can form the scaffold framework of the tree (fig. 7–17).

When the tops of young trees are killed, it is usually best to rebuild the top by favoring the growth of one strong shoot. The shoot chosen to form the new top should be forced into growth by pinching back other sprouts.

Occasionally trees are injured by hot, dry winds that burn or scorch foliage. Injured branches usually recover, although recovery may be slower than after frost damage. Branches which fail to recover should be pruned in such a way that a minimum loss of foliage occurs.

Another common form of injury is gopher or rodent damage to trees. Normally such trees are healthy; unless a tree is badly girdled, it will recover. If damage is so extensive that the remaining root system is unable to supply enough water for the top, then top-root balance should be restored by pruning.

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Pruning Practices in Special Areas

Most of the pruning practices discussed so far in this chapter are applicable to citrus culture in general. In some of the world's citrus-growing areas, special problems have resulted in the development of pruning methods tailored to individual needs.

Spain.—The Spanish method of pruning orange trees is diametrically opposed to the limited pruning that has been traditionally recommended for the care of orange trees in California. The Spanish pruning method has been developed over a long period of time and appears well suited to that country's methods of culture.

The primary objective in the growth of a Spanish orange tree is development of a good scaffold structure. Early fruiting is secondary, and young trees are heavily fertilized to cause vegetative growth. Early pruning consists of nipping back shoots that are growing at the expense of wanted limbs and removing badly placed or surplus branches. Sometimes reed canes are used to brace and train branches to grow in the desired direction.

Ideally, the trunk is forced to divide into two main scaffold branches about 18 inches above the ground. This is achieved by topping at the desired height and permitting only the two laterals in the best position to develop (fig. 7–18). By means of pruning, each of these branches is caused to divide into two limbs at right angles to the plane of the branching of the trunk. Each of these branches is again forced to divide at right angles to the previous branching, and so on. This type of scaffold structure promotes a low spreading tree with an open center.

Trees are pruned frequently, but never excessively at any one time. Spanish recommendations call for removing unwanted growth before it reaches a length of eight inches. Removal of larger wood depletes a young tree excessively. When branches are removed, cuts are made flush at the point where an unwanted branch arises from its mother limb.

Pruning for scaffold structure delays fruiting, and most trees do not come into bearing until they are about seven years old. Once a scaffold structure is formed, attention is given to pruning for fruit production.

Pruning for fruit production is based on the premise that fruit should be distributed throughout the canopy of the tree. This interior fruit is smoother and of better quality. It is also less susceptible to damage by frost and wind (fig. 7–19). Pruning is directed toward the removal of weak, unproductive wood, badly directed or placed branches, small branches that interfere with light reaching the center of the tree, and suckers borne on the trunk or arising from the center of the tree that are not needed for training into scaffold or fruiting branches.

Well-placed young shoots and new growth are not pruned. Suckers or small interior branches are headed or bent over to force them to branch

Fig. 7–18. Forked trunk typical of Spanish citrus pruning results in a tree with an open spreading, scaffold structure.

Fig. 7–19. An annual pruning keeps the center open for light penetration and the setting of inside fruit.

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and become fruitful. Since the skirt of a tree is the heavy bearer of high-quality fruit, particular attention is given to development of hanging skirt branches. These are renewed by undercutting of the lower and older wood, with the growth of new wood along the top of the hanging branches. Undercutting also keeps the skirts high enough so that low-hanging fruit does not touch the ground where it would rot as a result of the flood-irrigation system used in Spanish orchards. In many cases, skirt branches heavily laden with fruit are propped. Skirt branches are also kept off the ground as an aid to tillage.

Spanish trees are pruned annually and sometimes more often during their formative stage. A wide difference of opinion exists among Spanish growers as to how severe pruning should be, but all of them agree that some pruning is necessary and that it is important that pruning be a continuing operation that does not remove too much vegetative growth and wood at one time, since an adequate number of leaves are needed for new wood and fruit production.

Differences in tree vigor may be one reason why pruning is so successfully used in Spain and not in California. This may be explained in a simplified manner by comparing what is known as "old-line" and "young-line" or nucellar vigor. Budlines in Spain are quite old. Although vegetative reproduction by budding rejuvenates the young tree which develops from the bud, this rejuvenation is not as great when reproduction is made through the seed, whether sexual or nucellar.

As trees age and as repeated generations are formed by budding, there is a tendency for the line to become less vigorous. Latent viruses also may be present which are transmitted through the budwood, resulting in a decrease in vigor. Pruning stimulates new growth and causes an increase in vigor which is needed for fruit production.

In Spain, a distinction is made between varieties on the basis of the amount of pruning required. Blood oranges, which are low in vigor, are pruned more heavily than more vigorous navel and other white-fleshed varieties.

Spanish orange trees enter production at a later age than California trees. They bear crops of good-sized, high-quality fruit. Since Spanish trees are smaller than those in California, production per tree is lower (which may also be a result of pruning). Lower production, however, is compensated for by orchards containing a greater number of trees per acre. On an acreage basis, Spanish production compares favorably with that of California groves. According to the Spanish, pruning reduces the alternate-bearing tendency of some varieties and usually results in larger fruit.

Spanish methods have influenced practices in Algeria and Morocco, particularly in the culture of Clementines, mandarins, and tangerines (Burke, 1952). Algerian growers believe they must prune tangerines to get fruit of commercial size, although Burke noted good fruit on unpruned trees. Burke also suggested that heavier pruning in these countries than in California may be a benefit in disease control. The open trees permit light penetration and air movement, which may have a tendency to reduce damage from gummosis and other fungal diseases stimulated by moisture.

Sicily.—In Sicily, density of trees in orchards is high, averaging about 200 per acre, although recent plantings usually contain 160 trees per acre. Occasionally, an extremely old orchard has as many as 600 trees per acre.

In closely planted Sicilian orchards, pruning is carried out to limit tree size and open trees to light penetration. Weak and unproductive wood is removed; branches that enhance vigor and production are left. In newer orchards, where

Fig. 7–20. Three-foot budding height leaves these Sicilian trees free of the full skirts typical of California orchards.

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trees are more widely spaced, pruning is not as heavy.

Sicilian citrus is grown on sour orange rootstock, generally budded at a height of one meter. This height is probably a holdover resulting from fear of gummosis, which almost wiped out the Sicilian industry at a time when trees were propagated from cuttings and planted on their own roots. Because of such high budding, skirt formation develops slowly. In the denser orchards, shading may occur before skirts are formed (fig. 7–20).

Israel.—Pruning methods employed in new orchards in Israel are similar to those in California. Israeli citrus specialists advocate planting at least 120 trees per acre for optimum production of the Shamouti variety, which makes up 60 per cent of the plantings of Israel. Fewer than 120 trees per acre have been found to reduce per-acre yield. Some growers plant 240 trees per acre and thin them to 120 trees twelve years after planting. If left unpruned too long, trees crowd together, the skirts shade out, and a fruit-producing canopy forms in the tops of trees. In some orchards, mechanical hedging is employed to keep rows open and prevent loss of skirts.

Japan.—In Japan, trees are often cut back to 18 inches or less at planting to help prevent wind damage (Bitters, 1964). Orchard trees are staked and trained to develop three main scaffold branches; all other branches are removed. The Japanese plant as many as 1,200 trees per acre, thinning them as crowding occurs. On deep fertile soils, plantings are usually about 300 trees per acre after thinning; on shallow, rocky soils, 600 trees per acre are common. Considerable pruning is required to keep such trees small and well trained.

Pruning practices in Australia and New Zealand are similar to those in the United States. Growers have recently begun hedging of crowded orchards in a few locations.

GIRDLING OF CITRUS

Some citrus varieties set poor crops of fruit because of inadequate pollination and fertilization of the ovule. This is usually due to self-incompatibility or a lack of viable pollen. In either instance, most of the fruit set will be parthenocarpic—fruit developed without seeds. The practice known as "girdling" or "ringing" appears to increase the set of such fruit, as well as seeded fruit. The ultimate effectiveness of girdling, however, still remains open to doubt.

Physiology

The type of girdling discussed here is a single knife cut all the way around the base of the citrus tree that severs the phloem and bark without removing tissue (fig. 7–21). The resulting break in the phloem heals quickly but is sufficient to stimulate an increase in fruit set. Furr, Reece, and Hrnciar (1945) found that there is a return to normal nutrient absorption two weeks after girdling, which indicates that the break in phloem tissue may last less than two weeks.

The physiology of this type of girdling is not understood. Most studies of girdling physiology have been concerned with a more severe cut, including the removal of a band of bark and phloem tissue from the tree trunk. Such girdling heals slowly over several weeks or even months. Carbohydrates and organic acids usually accumulate in the tissue above the band, and nitrogen and total ash below it (Meyer and Anderson, 1952). Since the single cut also severs the phloem tissue, the effect of such girdling may also be due to a

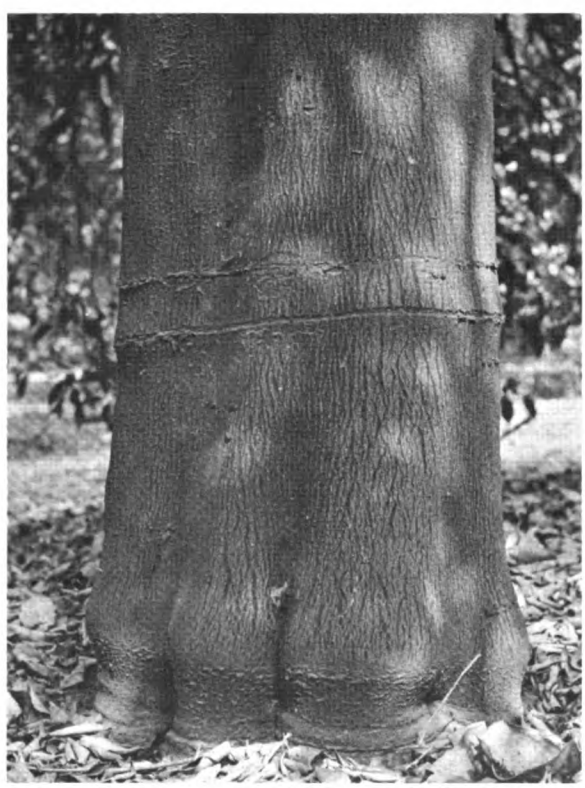

Fig. 7–21. This citrus tree has been girdled twice in past years as shown by the scars. It is not uncommon to find up to a dozen such scars on trees in very old groves.

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change in the carbohydrate-nitrogen levels, although the evidence suggests otherwise.

Curtis and Clark (1950) reported that regeneration of new phloem within 10 to 15 days resulted in translocation so nearly normal that no difference could be measured between control and treated shoots in analyses for sugar, starch, nitrogen, and ash. Murneek (1941) showed that apple fruit set was increased an equal amount whether girdling affected carbohydrate and nitrogen levels or not. Thus, carbohydrate and nitrogen levels appear to be of little importance in single-knife-cut girdling. It appears possible that severance of phloem tissue causes a temporary increase or decrease in a growth regulator influencing fruit set. The value of girdling in parthenocarpic fruit set seems to support this hypothesis.

In Spain, Gonzales-Sicilia (1963) stated that girdling has been used with success to increase fruit set of the Clementine mandarin. Common practice is to girdle the base of selected branches rather than the trunk. The Sanguina varieties have not benefited from girdling. However, girdling of low-producing navel and Cadenera varieties has produced better quality fruit and increased inside fruit set.

Time of Girdling

To increase fruit set, girdling is usually performed soon after full bloom. Krezdorn (1961*b*) reported that the response was about the same if cutting was done at full bloom, two-thirds petal fall, or petal fall plus two or three weeks. Experiments performed by the authors indicated that petal fall is a satisfactory time for girdling. Shamel (1932) obtained the best results when trees were girdled at the end of the bloom period.

Effects of Girdling

Almost invariably, the response of citrus trees to girdling in the first year has been encouraging. Agreement is lacking, however, on what happens in subsequent years. In South Africa, Allwright (1936) girdled 14-year-old Washington navel orange trees annually and reported an average increased production of 14 per cent the first year, 4 per cent the second, about 2.5 per cent the third, and a decrease of about 5 per cent in the fourth year. When Allwright girdled trees for one year only, production declined 13 per cent in the second year after girdling. Shamel and Pomeroy (1933*b*, 1934, 1935) reported similar results with Valencia and Washington navel oranges. They concluded that girdling for three to four years initially increased yields, but eventually resulted in a production drop. Most reports have indicated there is no effect on fruit size due to girdling, although Shamel (1944) reported one case of decreased fruit size on girdled trees.

The authors, working with four-year-old Washington navel orange trees, observed an increase in production the first year after girdling, but subsequent yields decreased sufficiently to suggest that the practice may be detrimental to trees of that age. Fruit size did not seem to be affected.

In Florida, Orlando and Minneola tangelos and Clementine mandarins bear sparsely because of self-incompatibility of pollen and the lack of proper pollinators. Krezdorn (1961*a*) reported a large increase in production after girdling of Orlando trees, although fruit was smaller than for seeded fruit. Girdling of Clementine mandarins also resulted in increased production, but fruit size was small.

Caution should always be exercised in girdling. On four- to five-year-old Washington navel orange trees, severe girdling into xylem tissue resulted in the death of about twenty trees in an orchard in Riverside, California. Krezdorn (1961*b*) called attention to the importance of good tree vigor and good bloom for successful girdling. Some growers in Florida, according to Krezdorn, have observed scaling and gumming at the girdles of old Valencia and navel trees that showed leaf symptoms of psorosis. Krezdorn also feels it is possible that girdling provides an entrance for the foot-rot organism. In areas where this disease is a problem, care should be taken to girdle higher on the trunk.

The question of whether or not girdling produces greater returns for the citrus grower over a period of years remains unresolved. Some authorities have argued that phloem regeneration is never complete after girdling and that the practice slowly reduces the translocation capacity of the tree.

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LITERATURE CITED

ALLWRIGHT, W. J. 1936. Girdling Washington navel trees. Citrus Grow. **46**:7, 9, 10, 11, 13, 15.

BITTERS, W. P. 1964. Citrus rootstocks and nursery practices in Japan. Calif. Citrog. **49**:205–10.

BLANCHARD, V. P. 1930. Securing early production with young lemon trees. Calif. Citrog. **15**:441, 478–79, 484.

——— 1931. Analyzing the advantages and faults of "heading-back" and "thinning-out" systems of lemon pruning. Citrus Leaves **11**(2):1–3.

——— 1932. Training young citrus trees. Calif. Citrog. **17**:445, 470–72.

BOWMAN, F. T. 1956. Citrus growing in Australia. Angus and Robertson, Sydney. 311 pp.

BURKE, J. H. 1952. The citrus industries of North Africa. U. S. Dept. Agr. For. Agr. Rept. **66**: 152 pp.

CAMERON, S. H. 1933. Starch in the young orange tree. Proc. Amer. Soc. Hort. Sci. **29**:110–14.

CAMERON, S. H., and R. W. HODGSON. 1941. Effect of severity of pruning on top regeneration in citrus trees. Proc. Amer. Soc. Hort. Sci. **39**:67–72.

——— 1943. Effect of time of pruning on the rate of top regeneration of Valencia orange trees. Proc. Amer. Soc. Hort. Sci. **42**:280–82.

CURTIS, O. F., and D. G. CLARK. 1950. An introduction to plant physiology. McGraw-Hill Book Co., Inc., New York. 752 pp.

FURR, J. R., P. C. REECE, and G. HRNCIAR. 1945. Nitrogen absorption of ringed orange trees in sand culture. Proc. Amer. Soc. Hort. Sci. **46**:51–54.

GONZALES-SICILIA, E. 1963. El cultivo de los agrios. Second edition. Instituto Nacional de Investigaciones Agronomicos, Madrid. 805 pp.

HALMA, F. F. 1923. Influence of position on production of laterals by branches. Calif. Citrog. **8**:146, 180.

IWASAKI, T., and M. NISHUIRA. 1952. Influence of shading and submersing on fruit drop of citrus. Bul. Hort. Div. Tôkai-Kinki Agr. Expt. Sta. **1**:49–60.

JOHNSTON, J. C. 1963. Treatment of frost injured trees. Calif. Citrog. **48**:106, 116, 117, 119.

KRAUS, E. J., and A. R. KRAYBILL. 1918. Vegetation and reproduction with special reference to the tomato. Oregon Agr. Expt. Sta. Bul. **149**: 90 pp.

KRETCHMAN, D. W., and P. J. JUTRAS. 1962. The influence of pruning on size and quality of Florida grapefruit. Proc. Fla. State Hort. Soc. **75**:35–42.

KRETCHMAN, D. W., and A. H. KREZDORN. 1961. Recent developments in pruning citrus. Proc. Fla. State Hort. Soc. **74**:67–74.

KREZDORN, A. H. 1961*a*. Girdling increases yield of seedless Orlando tangelos. Fla. Univ. Agr. Expt. Sta. Res. Rept. **6**(1):7.

——— 1961*b*. Girdling to increase fruit set—use it cautiously. Citrus Indus. **42**(7):20–21.

KREZDORN, A. H., P. J. JUTRAS, and D. W. KRETCHMAN. 1961. Small power tools for pruning citrus. Fla. Univ. Agr. Ext. Serv. Circ. **211**: 12 pp.

LEE, B. W. 1962. Hedging and topping of mature Valencia orange trees. Calif. Citrog. **48**:42, 52, 53.

LEWIS, L. N., C. D. MCCARTY, and P. W. MOORE. 1963. Effects of skeletonization on the rejuvenation and production of declining orange trees. Proc. Amer. Soc. Hort. Sci. **83**:295–99.

MENDEL, K. 1950. Studies on the vitality of orange branches. Jewish Agency for Palestine Agr. Res. Sta. Bul. **57**:19–23.

MEYER, B. S., and D. B. ANDERSON. 1952. Plant physiology. D. Van Nostrand Co., Inc., Princeton. 784 pp.

MONSELISE, S. P. 1951. Light distribution in citrus trees. Bul. Res. Coun. Israel **1**(3):36–53.

MOORE, P. W. 1957. Some results of pruning experiments with old orange trees. Citrus Leaves **37**(2):6, 7, 23.

——— 1958. Mechanical pruning for citrus. Calif. Agr. **12**(11):7–9.

MURNEEK, A. E. 1941. Relative carbohydrate and nitrogen concentration in new tissues produced on ringed branches. Proc. Amer. Soc. Hort. Sci. **38**:133–36.

OPPENHEIMER, H. R. 1950. Studies on the reestablishment of citrus groves during the second World War. Jewish Agency for Palestine Agr. Res. Sta. Bul. **54**:3–23.

PROSSER, D. S., JR. 1953. Hedging machine for citrus groves. Fla. Agr. Expt. Sta. Bul. **519**: 11 pp.

REED, H. S. 1917. Comparative results of moderate and severe pruning. Calif. Citrog. **3**:25, 38.

REED, H. S., and F. F. HALMA. 1919. On the existence of a growth-inhibiting substance in the Chinese lemon. Univ. Calif. Pubs. Agr. Sci. **4**:99–112.

SHAMEL, A. D. 1919. Some results from an experiment with pruning as compared with no pruning of full bearing Washington navel trees. Calif. Citrog. **4**: 174–75.

——— 1920*a*. Results of five years' individual tree performance records with pruned and unpruned lemon trees. Calif. Citrog. **5**:102, 122–23, 128.

——— 1920*b*. Results of individual tree performance record studies with pruned and unpruned Marsh grapefruit trees. Calif. Citrog. **5**:248, 268–69.

——— 1925. Performance records of pruned and unpruned Washington navel trees for a period of ten years. Calif. Citrog. **10**:415, 442–43, 445.

——— 1927. Pruning of citrus trees in California. Calif. Citrog. **13**:3, 18–20.

——— 1929. Washington navel pruning and girdling experiments. Calif. Citrog. **14**:335, 376, 382.

——— 1932. Performance of girdled and not girdled navel orange trees. Calif. Citrog. **18**:38, 62.

——— 1944. Effects of trunk girdling on navel orange trees. Calif. Citrog. **29**:230–31.

SHAMEL, A. D., and C. S. POMEROY. 1933*a*. Eureka lemon pruning test. Calif. Citrog. **18**:218, 236.

——— 1933*b*. Girdled Washington navel orange trees. Calif Citrog. **18**:328, 347–48.

——— 1934. Girdling Valencia orange trees. Calif. Citrog. **19**:176, 186.

——— 1935. Progress report on girdling Washington navel orange trees. Calif. Citrog. **16**:94, 101.

——— 1942. Effects of pruning old Washington navel orange trees. Proc. Amer. Soc. Hort. Sci. **41**:71–76.

SITES, J. W., and H. J. REITZ. 1949. The variation in individual Valencia oranges from different locations of the tree as a guide to sampling methods and spot-picking for quality. I. Soluble solids in the juice. Proc. Amer. Soc. Hort. Sci. **54**:1–10.

SURR, G. 1919. Yields of Washington navel oranges in relation to pruning. Calif. Citrog. **4**:290, 325.

WEBBER, H. J. 1919. A study of the effects of freezes on citrus in California. Univ. Calif. Agr. Expt. Sta. Bul. **304**:249–321.

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CHAPTER 8

Irrigation

A. W. MARSH

IRRIGATION IS FREQUENTLY the most costly, repetitive, and time-consuming cultural practice involved in growing citrus in arid and semiarid climates with lengthy dry periods. Even in subhumid and humid climates irrigation is used increasingly to maintain yields that would otherwise be reduced by short- or medium-length dry periods. The purpose of this chapter is to stress the importance of good irrigation in citrus production, explain its basic principles, and provide useful information on its biological, physical, and mechanical relationships.

Citrus trees are sensitive in many ways to their physical environment. They react adversely to excessive heat, frost, dry soil, excessively wet soil, low soil oxygen, and air pollution. Poor irrigation is a direct cause of dry or excessively wet soil and a strongly contributing cause of low soil oxygen. Damage from excessive heat has commonly been observed to be greater in poorly irrigated orchards than in those that have been well irrigated.

Because of increasing competition for citrus markets and rapidly rising production costs in most areas, high fruit yields of good quality are essential to a profitable enterprise. It has been shown that good irrigation must be practiced to obtain high yields (Taylor, 1941). It also has been demonstrated that pest control, pruning, and fertilization improvements do not lead to high yields if irrigation practices are inferior. When such improved cultural practices are combined with good irrigation, yield increases can be obtained.

If citrus raising is to remain profitable in high-cost areas, efficient irrigation is absolutely necessary. Merely running the water in a routine fashion is not sufficient. Irrigation should be carefully supervised by intelligent, well-trained persons employing modern ideas, techniques, and equipment.

SOIL-WATER SYSTEM

The principal direct effect of irrigation is the addition of water to the soil-water system. The effect on the tree is brought about by conditions existing in the soil-water system after an irrigation. Some knowledge of the soil-water system is therefore desirable in understanding how irrigation affects citrus trees.

Soil-Water Retention

Soil consists of various-sized solid particles and the spaces between them, which are called pores. Coarse, medium, and fine solid particles are known as sand, silt, and clay, respectively. Soils on which citrus is growing may contain an amount of pores ranging from 40 to 55 per cent of the total soil volume. These pores hold the water and air that are so necessary to citrus roots.

Water is held in the soil pores by attraction between the water molecules and the surfaces of the solid particles. At a low water content, water is spread as a thin film over the surfaces of all the soil particles. The thinness of the film is dependent upon the amount of water present and the total surface area of all the solid particles. Fine-textured (clay) soils have a greater particle surface area than coarse-textured (sandy) soils, so that a given amount of water is spread in thin-

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ner films. An illustration of the total surface area of one pound of various-textured soils of California is presented below.

Soil Type	*Surface Area*[1] *(Acres per Pound)*
Chino clay	22.4
Yolo loam	4.4
Sorrento fine sandy loam	2.2
Ramona sandy loam	0.5

When water films are thin, water molecules are very close to the particle surfaces and are held tightly. The security with which water is held is sometimes expressed in energy units (joules per kilogram) which represent the energy that must be expended to remove a definite amount of water from the soil (Taylor, Evans, and Kemper, 1961). This energy is more commonly expressed in pressure units of bars or atmospheres, which are about equal numerically, and is called soil suction or soil-moisture tension.

When all of the pore space is filled with water, a soil is saturated. The energy required to remove a unit of water from saturated soil is low, and some water drains from the soil by gravity. Drainage removes water from the largest pores, where it is held least securely, and air space is created in these pores. The remaining water is somewhat closer to the soil particles' surfaces and is held firmly enough to prevent rapid drainage by gravity. This water condition, when measured in the field, is called field capacity.

In the process of water use by plants, first the medium and eventually the smaller soil pores lose water. Water films gradually become thinner, and a greater energy is required to remove each subsequent increment of water. At first the change in energy requirement is slight and has little effect on the plant. Since citrus roots do not come in contact with every particle of soil in the root zone, water must move through the soil to reach root surfaces. The distance traveled may be no more than one or two millimeters or it may be several centimeters. Water moves more rapidly in thick films than in thin films. As water films become thinner, the rate of flow decreases and eventually becomes too slow to meet the needs of the tree. The physical availability of soil water to a citrus tree is a continuously variable characteristic largely depending on the water film thickness.

When soil-water films become so thin that the tree wilts and remains wilted overnight, the soil-water condition is at the permanent wilting point. Citrus will generally suffer daytime wilting repeatedly before this condition is reached.

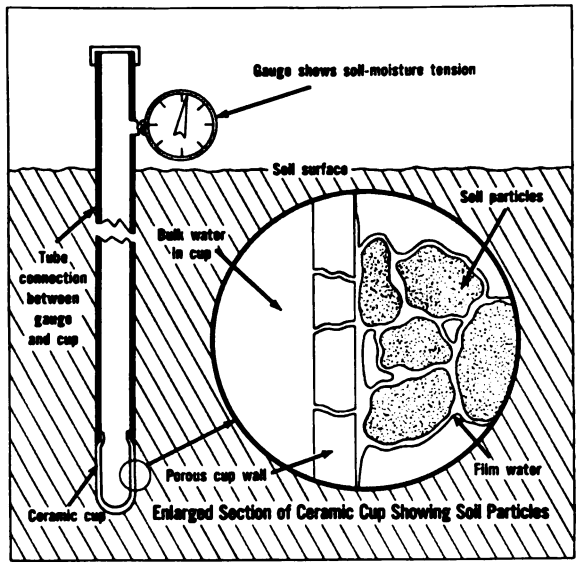

Fig. 8–1. Cross-section of a tensiometer. Essential parts include porous cup, connecting tube, vacuum gauge, and removable stopper or cap. The enlarged section schematic diagram shows how water films surrounding soil particles connect with bulk water in the tensiometer. (From Richards and Hagan, 1958.)

Soil-Water Measurement

From the preceding discussion, it is apparent that water film thickness in the root-zone soil of a citrus tree is an important consideration. Much attention has been devoted to water film thickness in recent years. Instruments have been developed to measure soil suction, which is directly related to water film thickness. These instruments utilize a porous material placed in contact with the soil to be measured. Water moves until the films in the porous material of the instrument and in the adjacent soil are of equal thickness. The indicating portion of the instrument registers the effect produced by the film thickness.

Instruments in common use at present are of two types: tensiometers and electrical-resistance blocks. L. A. Richards and M. R. Huberty (1941) probably initiated the use of tensiometers for measuring soil-water conditions in citrus orchards. The tensiometer is a closed, water-filled tube with a hollow, porous ceramic tip at one end and a vacuum gauge at the other. Water films in the ceramic tip exert a suction on the closed water

[1] Calculated from Bower and Gschwend (1952) and Richards, Weeks, and Warneke (1960).

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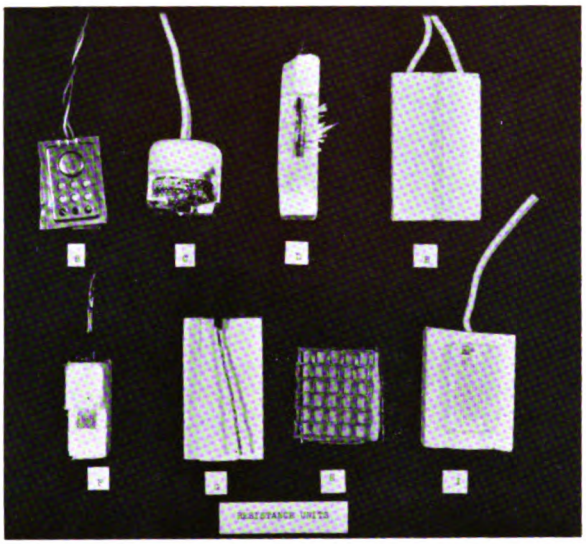

Fig. 8–2. Electrical-resistance blocks. Cutaway sections show electrode types and positions in various blocks. Soil water films enter block pores and conduct current between electrodes. (Courtesy of G. H. Cannell.)

column, which registers on the vacuum gauge (fig. 8–1). On commercial tensiometers, the vacuum gauges read directly in centibars (cb) of soil suction or moisture tension. Tensiometers operate in the wetter portion of the soil-water spectrum from saturation (zero suction) to a dryness of about 80 cb. This covers the range of greatest interest to most citrus growers for two reasons: (1) saturation is a dangerous condition for citrus trees which should be known and should not exist more than a few hours at a time during the active growing season; and (2) in most orchards, irrigation is desirable to avoid adverse effects in severe weather before a soil suction of 80 cb is reached in the major root zone.

Electrical-resistance blocks, composed of a cast-gypsum, porous material, are another means used in irrigation to measure the soil-water condition (fig. 8–2). They are installed in the root zone and exchange water films with the soil. The gypsum dissolves slightly in the moisture films contained in its pores. The dissolved gypsum then acts as a conductor for an electric current applied between two electrodes embedded in the porous gypsum. The amount of current conducted is indicated on a meter. Thick water films dissolve more gypsum and conduct more current with less resistance than thin water films. Gypsum blocks operate in the drier portion of the soil-moisture spectrum from about 50 to 1,500 cb. Since this range is not the one of greatest interest to most citrus growers, gypsum blocks have not been used extensively in citrus. With certain conditions, such as deep, fine-textured soil and mild climate, some citrus growers might desire to withhold irrigation until a dryness of 100 to 200 cb is reached. The electrical-resistance block would be the proper instrument for measuring these conditions.

An important point is that both classes of instruments give readings related to water film thickness or soil suction and are largely independent of the soil type in which they are installed. Also important are the ease with which measurements are made and the ability to minimize error by repeating readings at the same spot.

Up to this point, we have been concerned with the physical condition of water in the soil and its relationship to plant performance. It is sometimes desirable to consider the quantity of water in soil. It should be remembered that a knowledge of the quantity of water in a soil reveals nothing about its relationship to plant performance until it is calibrated in terms of the water-retention properties of the particular soil involved. Since all soils differ in water-retention characteristics, this calibration is required for every site at which a quantitative measurement is made if plant relations are of concern. However, useful engineering information can be obtained from water-quantity measurements.

To design an irrigation system either for a single, small field or for an entire irrigation district, information is needed about the rate at which water is used from the soil by evapotranspiration and the amount of water that can be usefully stored in the soil root zone. Pillsbury, Compton, and Picker (1944) measured the quantity of water in soil under citrus trees at successive dates between irrigations. The difference in water content of the soil between two successive measurements represents the evapotranspiration in a known time interval. A succession of soil-water quantity measurements made over an extended period of time provides information on the water-use rate in the area studied. These data can be used in designing the delivery capacities of irrigation systems.

The amount of water that can presumably be stored by a soil is determined by making measurements of water content after the soil has been thoroughly wetted and drained, and again when the trees have dried the soil as much as seems desirable. The difference in water content throughout the entire root zone between these

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two samplings gives the maximum amount of water that can be applied to the soil without loss by deep percolation. This total water-storage factor combined with the water-use rates provides an estimate of the allowable interval between irrigations on which an engineer can base design calculations.

The storage capacity of the soil in the root zone, as determined from water-quantity measurements, is sometimes useful in evaluating the efficiency of an irrigation. If computation of the approximate storage capacity of the soil shows that it can retain an irrigation of about 3½ inches (acre-inches per acre) in the root zone and a computation of the water application shows that 6 inches of water were applied, the inefficiency and waste from the application are quickly revealed.

Water-quantity measurements usually are made by two distinct methods. The older, most used method involves withdrawal of a sample of soil from a known depth in the root zone with a soil tube or auger. The sample is weighed while wet and again after being thoroughly dried. The loss of water upon drying, divided by dry weight of the soil, gives the weight ratio of water in the soil. When this figure is multiplied by the bulk density of the soil Lutz (1965), determined from a separate measurement, the volume ratio of water in the soil is obtained. This volume ratio multiplied by the length of soil column sampled gives the depth of water held in the soil. Because soils vary from one location to another and because soil moisture samples are usually compared between two different sampling dates with samples taken from different positions in the soil, it is necessary to replicate the sampling several times for any given site to obtain satisfactory results. The method of sampling plus the required replication makes the process laborious, and therefore its use is somewhat restricted.

Since about 1952, a method called neutron thermalizing has been used by research scientists and is described for use in citrus by Stolzy, Cahoon, and Szuszkiewicz (1957), Cahoon and Stolzy (1959, 1960), and Koo (1961). It involves the insertion of a probe carrying a source of fast neutrons into an access hole previously installed in the soil. The fast neutrons travelling from the probe out into the soil are converted to slow neutrons when they strike water molecules. The instrument carrying the source of fast neutrons also carries a detector for slow neutrons. As slow neutrons are deflected off the water molecules, a fraction of them return and are captured by the measuring device. The advantages of this system of measurement are: (1) ease and speed in making a large number of measurements, since only about two minutes per measurement are required; (2) the ability to make repeated measurements at the same site, so that variability is considerably reduced; and (3) the fact that measurements from a calibrated probe give values in terms of volume of water which are directly convertible to inches or centimeters depth without the necessity of making separate and laborious bulk-density determinations. The principle drawbacks to use of the neutron-thermalizing method are: (1) cost of the instrumentation; (2) complexity of the instrument, which requires a skilled operator; and (3) the mild radioactive hazard. For these reasons, the method is limited primarily to scientific and research personnel.

Movement of Water in Soil

The movement of water in soil is just as important as water retention in determining what the condition of the soil water will be during and after irrigations. Several characteristics of water movement are considered below, including infiltration, permeability, saturated flow, unsaturated flow, and impediments to water flow.

Infiltration.—Infiltration is a term that refers to the downward movement of water *into* the soil. When water falls on the ground from a rain or from a sprinkler system or flows across the ground in furrows or a basin, it enters the soil by the infiltration process. When the pores of the surface soil are large and remain open, infiltration may be a fairly rapid process. If the pores of the soil are small or if initially large pores become plugged, the infiltration rate will be slow, sometimes reaching values less than 0.1 inch per hour. An average infiltration rate in the range from ⅓ inch to 2 inches per hour will generally provide the greatest ease and efficiency of irrigation. Soils having infiltration rates above or below this range can be efficiently irrigated, but they require more attention, time, and special practices or equipment. Soils having rates of less than ⅓ inch per hour can be satisfactorily irrigated with low-application-rate sprinklers allowed to run for an extended period, or by furrows allowed to run for an extended period with special provision for handling the surface runoff. Infiltration rates greater than 2 inches per hour are no problem with sprinkler irrigation, but impose special requirements with surface irrigation. Large flows of water must be applied to relatively small areas

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for a short time if distribution is to be reasonably efficient. Whatever the infiltration rate for any particular soil, it constitutes one of the prime considerations in designing the irrigation system.

Generally, the infiltration rate is relatively high for a dry soil, steadily decreasing during the period of water application. This decrease in rates is caused by the increased resistance to water flow as the soil particles expand or swell and reduce the pore sizes. Sometimes the water application breaks down the surface soil structure, dislodging some of the fine soil particles from the soil aggregates to which they were previously attached. These fine particles then flow into the soil, plugging some of the pores. Another cause of the decrease in infiltration rate during irrigation is the increasing wetness of the soil, which lowers the hydraulic gradient (see explanation below). Reduction of infiltration rate with time is greater for medium- and fine-textured soils than it is for coarse-textured soils. This reduction of infiltration rate with time must be considered in sprinkler design (see page 275).

Permeability.—Permeability refers to the rate of movement of water *through* a soil and is frequently called hydraulic conductivity. It is defined as the rate at which a unit volume of water moves past a unit cross-section area of soil when driven by unit hydraulic gradient. Hydraulic gradient is the driving force which causes water to flow and results both from gravity and differences in wetness or soil suction. Gravity can only act downward and imparts a hydraulic gradient of 1, but the interaction of gravity with impermeable soil layers may provide movement obliquely downward, in which case the hydraulic gradient is less than 1. Difference in soil suction can move water in any direction and may provide large hydraulic gradients.

As with infiltration, permeability of a soil is dependent to a considerable extent on the pore sizes in the soil through which water can flow. With larger pore sizes, a more rapid rate of water flow will be obtained, and with soil having finer pores a slower rate of water movement will occur. When discussing hydraulic conductivity, there are two types of flow with different reactions to be considered. They are saturated and unsaturated flow.

Saturated flow refers to the flow of water through soil when all or most of the pores are filled with water. When saturation exists, the bulk of the flow takes place through the larger pores. Under saturated conditions, gravity is the driving force and the hydraulic gradient is about 1, which is small, so that the flow rate is primarily influenced by the size of the larger pores and their proportion in the soil. Saturated flow is therefore most rapid in coarse-textured soils.

Much of the time, water movement in soil takes place when the pores are not filled with water, and this is known as unsaturated flow. Unsaturated flow is essentially film flow, and its rate depends primarily on the thickness of the water films existing in the fine and medium pores. To some extent, the rate depends upon the hydraulic gradient, which is usually greater than 1 and may be many times greater if large differences in soil moisture condition exist in the soil profile. It is unsaturated or film flow which transports water from a point in the soil where it has not been depleted to a point where it has been depleted by root action. If water were unable to move in soil to the root surfaces by unsaturated flow, it would be necessary to keep the soil much wetter than is usually desirable to maintain a sufficient supply for plant use during periods of high evapotranspiration.

Coarse-textured soils have relatively poor unsaturated conductivity. Consequently, it is necessary to keep a coarse-textured soil wetter than a medium or fine-textured soil to obtain the same degree of plant response. Coarse-textured soils conduct water poorly by film flow because of their small surface area, which results in relatively few interconnecting water films.

Water moving in soil occasionally encounters a zone or soil condition where resistance to flow is great. While such a zone is rarely a complete block to all types of flow, it may retard flow to an extent which can be important in the soil-water system and in water-plant relations. Impeding zones can be grouped in three soil classes, representing the ways in which flow is retarded.

One class is characterized by a lack of large pores or, in extreme cases, by the near absence of pores. In normal soil, the rapid flow of water during irrigation or leaching takes place mainly through large pores. When a zone lacking large pores is encountered in the soil profile, the flow is reduced to a fraction of its previous rate and may stop entirely. The result is a "pile-up" of water, resulting in a perched water table which can be detrimental to plant roots. Leaching is difficult in this type of profile. Examples in this class include hardpans, tight clay layers, silt layers

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in sandy soil, and high-density layers, usually caused by compaction.

A second class is characterized by a discontinuity or drastic reduction of the medium and fine pores that carry films of water necessary for film flow. Compared to normal soil, this soil shows such a marked decrease in unsaturated hydraulic conductivity that unsaturated flow is almost nonexistent. Examples of this class include coarse-textured layers of either sand or organic matter underlying finer-textured soils, and vertical mulch layers covered over at the surface by fine materials.

If such layers are horizontal in the soil profile, water eventually accumulates just above the coarse-textured layer until saturation occurs at the boundary. If water continues to move down from above, free water will drip from the saturated layer into the coarser-textured material below so that no appreciable depth of perched water table is formed. However, even after downward flow has ceased, a saturated condition remains just above the textural interface until plant use or evaporation depletes it. Saturated layers can be harmful to plant roots and seldom contain roots of plants such as citrus which are sensitive to excessively wet conditions.

The third class represents a complete interruption of the conducting pores. It is based on the law of outflow of free water (Richards, 1950) which states: "Outflow of free water from soil occurs only if the pressure in the soil water exceeds atmospheric pressure." Such interruption occurs at the bottom of soil columns in soil mixes in pots or flats, laboratory soil columns, and lysimeters. In the field, pores are interrupted by tile lines, gopher tunnels, mole holes, and gravel or coarse sand layers underlying the soil. In no case will water leave the soil to enter large openings unless the soil is saturated at the point of outflow. Citrus growers considering installation of tile drainage should be aware of this characteristic. Tile drainage will not reduce the wetness of soil which is not saturated. Tile drains function only when they are located below a water table.

EFFECT OF IRRIGATION ON CITRUS

Irrigation exerts considerable influence on the root environment, affecting root growth, top growth, and yield of citrus. It also has some influence on the microclimate in the orchard. Irrigated orchards, except for a few on deep, porous, medium-textured soils, will not produce well under poor irrigation practices. On the other hand, there are many orchards growing in both coarse- and fine-textured, shallow soil which produce well when properly irrigated and managed.

Root Environment

Soil-Water Conditions.—The primary effect of irrigation is an alteration in the soil-water condition of the root zone. The extent of this alteration depends on the amount of water added, how it is added, and the permeability of the soil profile. Soil-water condition is a major component of the root environment, affecting the growth and health of roots (Cahoon *et al.*, 1957). Other components of the root environment affected by irrigation are soil aeration, temperature, and salinity.

The ideal environment for citrus roots is a porous, medium-textured, well-drained soil, where water is easily available but not in excess. When such a soil is irrigated, water distributes itself throughout the soil profile in the root zone or drains away leaving no excess. Many fine-textured soils transmit water slowly during an irrigation, so that there is a tendency for there to be a temporary period of excess water in the root zone. Such a tendency is not confined entirely to fine-textured soils. If coarse- or medium-textured soils are stratified, hindrance to the movement of water is created, as described earlier, and local zones of excess water may result. The growth and production of citrus may be impaired either by an excess of water in the root zone or by a lack of easily available water.

A deficiency of water in the root zone produces certain effects on root growth. As the soil drys, root growth becomes slower and eventually ceases. If some of the roots of a tree remain in soil containing easily available water, the roots in dry soil are not damaged. Hendrickson and Veihmeyer (1931) showed that plant roots do not grow through dry soil to reach wet soil, but remain healthy and ready to become active whenever the soil in which they exist receives moisture. In some orchards afflicted by repeated conditions of excess water, the most healthy roots are those existing in the portions of soil which remain dry from one rainy season to another. According to Stolzy (1960), trees suffering repeatedly from conditions of deficient water develop thicker feeder roots, which sometimes go to greater soil depths than those under trees maintained with more

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abundant soil-moisture conditions. Cahoon, Huberty, and Garber (1961) reported that trees irrigated at six-week intervals had more roots deeper in the profile, especially in the 2- and 3-foot soil depths, than trees irrigated at a three-week interval.

Excess water in the root zone exerts a much greater effect on the root system than a deficiency. Marsh (1958) stated that excess water application was the primary problem in the irrigation of citrus. Benton (1943*a*) reported that a decline of citrus-tree health resulting from excess applications of water is nearly always due to decay of fibrous or larger roots by *Phytophthora* spp. Stolzy *et al.* (1965) found that poor soil aeration, often caused by excess water, contributed to root decay of established plants independent of root-rotting fungi.

In a study of citrus decline, Cahoon, Harding, and Miller (1956) made a survey of good and poor orange orchards in the major California citrus areas. Their survey grouped high-yielding orchards, producing an average of 664 boxes per acre, and lower-yielding orchards, producing an average of 365 boxes per acre. Studies revealed more roots under the high-yielding trees. The low-yielding trees had about as many roots below the branches as the high-yielding trees, but the roots had declined seriously beneath the irrigation furrows. The implication is that soil under the furrows received excess water, which was directly or indirectly responsible for the declining root systems. Thomas (1922) noted that irrigation practice tends to follow arbitrary rules with insufficient knowledge of plant needs, and that excessive amounts of water are often used when water is available. Vaile (1924) found evidence of plant injury caused by excessive irrigation on heavy soil in the California coastal zone. Reed and Bartholomew (1930) observed that where excessive irrigation was practiced, particularly early in the spring, the root system was weakened. Hilgeman (1956) found that on a calcareous soil in the Salt River Valley of Arizona a chlorosis developed if the soil was kept uniformly wet throughout the year. Reuther and Crawford (1946, 1947) found that abundant irrigation of a calcareous soil in the Coachella Valley of California produced prominent chlorosis on grapefruit in the winter but not in summer. In a two-year experiment, the chlorosis was not detrimental to the growth and vigor of young trees, although it might have been over a longer period.

In most of the cases observed in California citrus orchards where root systems were unhealthy and weak, the available evidence indicated that excessive soil-water conditions existed, at least part of the time. The reasons for excessive water conditions usually were to be found either in the nature of the soil profile, which contained an impedance to water movement, or in the amount of water put on the soil with each irrigation. Sometimes irrigation runs were too long for adequate distribution, and sometimes application was of excessive duration merely because water was delivered by the irrigation company for a given number of hours and could not be diverted elsewhere until it was turned off.

It is increasingly evident that an excess soil-water condition is detrimental to the root system of citrus. Because of the detrimental effects of excess irrigation, some authorities have recommended underirrigation as a means of preserving root health and preventing decline of trees (Benton, 1934*b*). Recent work reveals that correction of the problem of excessive water application does not necessarily mean that the soil must be allowed to become dry. *Phytophthora* root-rotting organisms probably occur in most citrus soils, ready to attack the roots when the environmental conditions are more favorable to the organisms than to the roots. This occurs when the soil is saturated or nearly saturated. Stolzy *et al.* (1959) found that trees inoculated with *Phytophthora* used significantly less water than trees not infected and had a reduced growth rate and fewer roots. However, the infected trees grew better when irrigated at soil suctions of 9 cb (wet) than at 60 cb (dry), especially in the second year. While the wet treatment consisted of irrigation at rather low soil suctions, care was taken to avoid excessive irrigation. Drying out orchards to treat root rot is unnecessary if excess water application can be avoided.

Cahoon *et al.* (1964) reported that citrus root distribution and density can actually be maintained and improved under a relatively wet irrigation treatment as well as under a drier treatment if care is taken to avoid excess water in the root zone. Revising an old irrigation experiment where roots below 2 feet were sparse under the wet treatment, they applied water to both a wet treatment irrigated at 20 cb and a dry treatment irrigated at 100 cb in such a manner that excessive amounts of water were always avoided. Within three years, root density improved at the

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3- and 4-foot depth of the former wet treatment and was as satisfactory for the 20-cb treatment as for the drier 100-cb treatment. An adequate amount of water can be applied frequently enough to avoid any chance of tree stress and still not injure the root system, if care is taken to avoid excessive application.

Soil Aeration.—It has generally been assumed that citrus roots need good aeration, including a reasonable level of oxygen in the soil atmosphere. Spurling (1950) states that citrus roots need good soil aeration if they are to remain healthy. Most observers claim that citrus roots do poorly and become unhealthy wherever there has been an excess of water, and a condition of excess water in the soil will usually create poor aeration conditions. Reuther and Crawford (1947) found that abundant to excessive irrigation sharply reduced oxygen concentrations in the soil atmosphere during summer, especially in association with heavy organic amendments, but had little effect in the winter when chlorosis was most pronounced. The question of whether citrus roots are more sensitive than other tree roots to low oxygen levels in the soil atmosphere has not been settled. The work of Curtis (1949) showed they were slightly less sensitive than avocados. It has been established (Stolzy *et al.*, 1965) that low oxygen levels can produce damage to roots independent of pathologic organisms.

A review of soil oxygen and aeration research, including the physics of oxygen supply, mineral nutrition, and the effect of low soil oxygen on root pathogens, is presented in Chapter 3 of Volume II.

The evidence is strong that citrus roots suffer decline and fail to grow satisfactorily in a poorly aerated environment, and perform satisfactorily only in a well-aerated root environment. It is therefore important that citrus growers manage their operations to provide a well-aerated environment for the roots of trees. The best way to do this is to avoid operations that tend to disperse and compact surface soil and to irrigate in such a manner that the root zone does not approach saturation, at least during the main growing season. Letey *et al.* (1963) stated that low soil oxygen is most damaging to plants during hot weather. This is the period when oxygen needs are greatest as shown by Reuther and Crawford (1947). Increased temperature also reduces the solubility of oxygen in water. It is therefore particularly important to avoid excessive irrigations during hot weather. Heavy irrigations, if needed for salinity control, should be carried out during the cool season when oxygen requirements are low.

Soil Temperature.—The roots of citrus and the trees themselves respond to differences in soil temperature. Girton (1927) conducted a study of grapefruit roots under controlled temperature and light conditions and found that the roots grew best at soil temperatures of 26° C (79° F). As the temperature rose to 30° C (86° F), the growth rate dropped off 25 per cent, and at 34° C (93° F) the growth rate was reduced 90 per cent. As the temperature dropped lower than 26° C, the growth rate again was reduced, and below 20° C (68° F) little growth occurred (chap. 9).

That the water-supplying ability of citrus roots is affected by the temperature of the root environment was demonstrated by Bialoglowski (1937). He measured the transpiration rate of rooted lemon cuttings grown in various root-temperature environments with similar aerial environment. The transpiration rate increased as root temperatures varied from 5° C to 25° C (41° F to 77° F), then decreased with higher temperatures. This relationship is shown in figure 8–3.

As Bialoglowski has shown, low temperature can affect water absorption by roots as adversely as high temperature. There is ample evidence that soil temperatures fall low enough during cold winters to impair water absorption by the roots. Huberty (1948) reported that in the California freeze of 1937 the soil temperature at the 2-foot depth at the Riverside Citrus Experi-

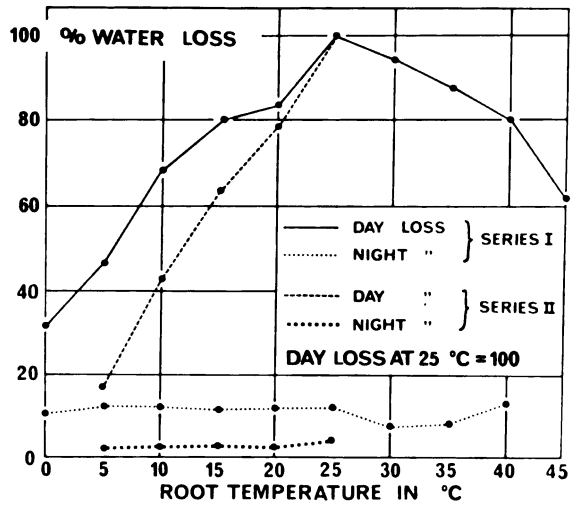

Fig. 8–3. Effect of root temperature on the rate of transpiration of rooted lemon cuttings. (From Bialoglowski, 1937).

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ment Station fell to 40° F (4.5° C). At the same time, the atmosphere was extremely dry, the minimum dew point reaching –8° F (–22° C). The trees were severely wilted, and leaf-saturation deficits (see p. 239) exceeding 20 per cent were measured.

If water appreciably warmer than the soil temperature is available, irrigation may be of some benefit in relieving stress caused by a combination of high evaporative conditions in the aerial environment and low temperatures in the root environment. If, however, the irrigation water has a temperature little different from that of the soil in the root zone and if the soil contains a satisfactory supply of easily available water, there is little advantage to be gained from irrigating at such a time. There might possibly be some disadvantage, since warming of the soil could be retarded and excessive wetness created.

In hot, desert climates, the temperature in the upper 6 to 12 inches of soil may become very high during the day. Smith, Kinnison, and Carns (1931) found that transpiration of citrus virtually ceased when root temperatures reached 93° F (34° C), and that trees used much less water during the heat of midsummer than they did in the spring. They believe that soil temperature caused this reaction, since a large proportion of the total citrus root system exists in the upper soil layers subject to high temperatures during hot weather. Irrigation lowered the soil temperature in several tests in a range from 4° F to 10° F at 1-foot depth, 3° F to 5° F at 2 feet, and 1° F to 2° F at 3 feet. These temperature depressions gradually diminished with time after an irrigation, and were finally dissipated after about ten days. In an experiment in which the intervals between irrigation were varied by weekly increments of one to six weeks, they found a decreasing growth of citrus from the first to the sixth treatment. Since the soil in the two-week-interval treatment had adequate available moisture at all times, but trees still did not grow as well as on the one-week interval, they assumed that the difference must have been caused by lower soil temperatures in the more frequently irrigated plots.

The summation of evidence on the effect of irrigation on the root environment, including soil-water condition, soil aeration, and soil temperature, suggests that a summertime irrigation program might well consist of frequent light irrigations in the hot climates and less frequent, slightly heavier irrigations in cooler climates. The amount of water applied should not be sufficient to create saturated or near-saturated conditions in the root zone.

Effect of Irrigation on Top Growth

The top growth of a citrus tree often reflects what is taking place in the root environment. In reviewing the literature, one is impressed with the confidence many investigators place in top growth as a reliable means of evaluating the effects produced by different management practices. Because of the ease of handling large numbers of carefully selected uniform plants, many researchers use citrus seedlings and evaluate the results of their irrigation and other management variables on top growth alone.

Smith *et al.* (1931) evaluated their irrigation variables in terms of top and root growth. Yearly top growth was obtained by measuring the trunk circumference of each tree. After two or three years of growth, certain border trees were removed and the entire top and root system weighed. The actual increase in trunk diameter was greatest on a plot irrigated at weekly intervals and was progressively less on other plots, each of which had an irrigation interval one week greater than the preceding treatment. The difference in trunk growth between the most frequently irrigated and the least frequently irrigated trees became greater with each suceeding year. Halma (1935) conducted an experiment in which two irrigation frequencies were studied. He measured both trunk growth and leaf-saturation deficit (see p. 239). Leaf-saturation deficit was less and trunk growth greater on the more frequently irrigated treatment. An interesting observation from this study was that on a hot day of 117° F (47° C), not long after an irrigation, the leaf-saturation deficit was 4.84 per cent. Later in the irrigation cycle, when the soil-water content was much lower, a leaf-saturation deficit of 8 per cent was recorded on a relatively mild day.

Samish (1957) conducted an irrigation experiment with grapefruit on sour orange rootstock in the interior of Israel where soils are fine-textured. Three irrigation treatments defined by moisture content in the second foot of soil were utilized. The wet, medium, and dry irrigation treatments received water, respectively, when 55, 71, and 87 per cent of the available moisture was depleted in the second foot. Irrigation differential treatments were begun when the trees were three years old and were continued through their

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Table 8–1
EFFECT OF IRRIGATION ON GROWTH OF SEVEN-YEAR-OLD GRAPEFRUIT TREES

Irrigation Data and Tree Response	Irrigation Treatment*			L.S.D. at 5 per cent†
	Wet	Medium	Dry	
Available water depletion (%)	55	71	87	.....
Amount of water applied, 4th to 6th year (inches/year)	24.6	16.8	10.4	.....
Trunk cross-sections (in.²)	22.8	20.0	17.0	0.9
Crown volume (ft³)	766	681	480	219
Yield total first five bearing years (lb/tree)	1,015	833	597	209

Source: Adapted from R. M. Samish (1957).
* Average annual rainfall for the fourth through sixth year was 14 inches (355 mm).
† Least significant difference at odds of greater than 19 to 1.

seventh year. Table 8–1 shows the effect of the treatments on the top growth. In spite of the fact that the trees did not run out of available moisture under any of the treatments, there was a progressive and material increase in both trunk cross-section and crown volume from the dry to the wet irrigation treatment.

Stress Effects.—Water stress and its effect on trees is a subject of much concern and discussion. Stress is the physiological condition to which a tree is subjected whenever the rate of water loss from the leaves by transpiration exceeds the rate at which water is absorbed by the root system. Lombard *et al.* (1965) described a method to measure stress in leaves. Leaves of the same age are picked complete with petioles and placed immediately in a tight container. In the laboratory, dust is removed and leaves are weighed to the nearest centigram. The petioles, but not the leaf surfaces, are submerged in water in a humid chamber for 24 hours, then wiped and reweighed. The leaves are then dried for 24 hours at 68° C. The gain in weight times 100, divided by the weight at saturation minus the dry weight, equals the leaf-saturation deficit in per cent. Leaf-saturation deficit (per cent) =

$$\frac{\text{Saturated weight} - \text{field weight} \times 100}{\text{Saturated weight} - \text{dry weight}}$$

Stress can be caused by various conditions. (1) A hot, dry, or windy day may remove water from the leaves at so rapid a rate that the tree is incapable of absorbing water through its roots fast enough to make up for the loss, particularly if the root zone is limited. Root zones are often limited by the nature of the soil in which the trees are grown, and sometimes further limited by management practices such as deep tillage and excessive irrigation. (2) A low soil-moisture condition may reduce the availability of water, so that the roots cannot extract it without a very high hydraulic gradient existing between the root system and the leaves of the tree. This high hydraulic gradient creates a condition of stress. (3) A soil may be partially dry so that the hydraulic conductivity of the soil has been reduced materially, and after the roots have absorbed the water with which they are directly in contact, the replacement of this water by movement from points some distance away (these distances need not be more than a few millimeters) is not rapid enough to meet the needs of the tree. (4) Under certain conditions, it is possible for the root zone to be so wet that oxygen replenishment is difficult. The rate of water absorption by the tree is appreciably less when the oxygen level is low, which can cause stress on a day in which there is high transpiration. (5) Unfavorable root temperature and (6) sudden root injury such as that caused by deep plowing can also reduce water absorption rates and create stress.

Stress can occur in citrus trees before signs of water shortage are clearly evident. Furr and Taylor (1939) noted in California experiments that reduced growth and abnormal loss of leaves resulted when lemon trees were allowed to go without irrigation until signs of water shortage were evident. Furr (1955) noted that under hot desert conditions the growth of grapefruit with an active root zone of four to five feet in depth was first affected when the top foot of soil reached the wilting point.

There are other aspects of stress in citrus which have been given considerable attention by various investigators. One of these is fruit drop, called "June drop" in the northern hemisphere

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and "December drop" in the southern hemisphere. A citrus tree usually sets more fruit in the spring than it can reasonably bear to maturity. In late spring or early summer, abscission layers form at the base of the stem and some fruit is shed. High temperatures frequently occur as the excess fruit is shed. In years when this occurs, more fruit is shed than during years when high temperatures do not arrive until after the fruit-shedding period, according to Jones and Cree (1965). The abruptness of the high temperature has no influence on its effect. Though the early high temperatures usually cause a general fruit drop over the geographic area affected by the weather conditions, there are always some orchards affected more severely and others less severely than the average. Some observers have stated that previous irrigation practices are better in those orchards which retain more of the fruit.

Spurling (1950) stated that fruit drop was caused by improper frequency of irrigation. Trumble (1952) referred to the "December drop" in Australia's Murray River area. It was his contention that citrus roots are inefficient water absorbers, and therefore the soil must be kept fairly wet during this period to avoid stress, which presumably causes the fruit drop. He pointed out that medium to large fruit on the tree can buffer the stress, but small fruit does not have the capacity, and this is the reason fruit drop is more severe for navel oranges than for Valencias, which still carry the old crop. He admitted that the link between stress and fruit drop has not been definitely established, but recommended better watering as a means of reducing the drop. Furr (1955) found that drying the top 2 or 3 feet of soil to about the wilting point during the June-drop period resulted in heavy fruit drop and reduced yield.

Hammond (1956) presented quantitative data related to citrus-fruit drop in Florida. During a dry spring after a winter in which root zones received adequate water, plots irrigated on April 25 and May 8 showed a 62 per cent fruit drop between April 25 and May 18. Tensiometers placed at 1- and 2-foot depths in these plots mostly remained lower than 80 cb. Plots not irrigated during this spring period had a 92 per cent fruit drop between April 25 and May 18. In these latter plots, most of the tensiometers exceeded 80 cb by May 11.

Another tree symptom that has been related to water stress is twig dieback or leaf drop. Wedding and Erickson (1960) induced water stress on rooted orange cuttings in gallon cans. Though the leaves were not severely wilted, many dropped when irrigated, abscissing at the point of attachment to the petiole. Spurling (1950) reported that leaf drop in Australia like fruit drop is caused by improper frequency of irrigation. He stated that the danger period for citrus leaf drop starts with the fall rains, because after the first fall rains, growers often conclude that the irrigation season is finished and prepare for frost protection and other winter operations. Since trees continue to transpire moisture during the winter and the early rains may not have provided as much moisture as is often assumed, the soil can become quite dry and trees may suffer. This danger period continues until the new fruit crop is sufficiently developed to act as a moisture-supply reserve. Spurling noted that severe citrus leaf drop rarely follows a dry winter and spring during which irrigations have continued in a normal manner. Until more citrus growers recognize the need for an improved irrigation-frequency schedule, and request it from their water-delivery agencies, citrus leaf drop will continue to be a problem.

Klotz and DeWolfe (1959) studied twig dieback of citrus from the pathological standpoint and found that inoculations with organisms did not produce dieback symptoms though fungi have been identified in connection with twig dieback. They believe that the fungi arrive as secondary invaders to extend the physiological injury initiated by warm weather in early spring. At this time, foliage gives off moisture more rapidly than the cold, relatively inactive roots can supply it. In a further study, Klotz *et al.* (1962) observed that there was less dieback on oranges having trifoliate orange rootstocks than on those of adjacent trees having Cleopatra mandarin or Troyer citrange rootstocks. Possibly the smaller trees on trifoliate orange rootstocks deplete soil water less rapidly. It is believed that the injury originates from a combination of adverse factors, some of which could be controlled by proper management. It was suggested that application of spray materials be avoided when plants are in need of water or losing water rapidly.

Good irrigation is the most important operation in combating stress problems to which citrus trees are susceptible, such as fruit drop, leaf drop, and twig dieback. This is not merely a matter of timing a single irrigation just before the maximum danger period. Proper water manage-

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ment is necessary throughout the year to build up a dense, healthy root system and a vigorous tree. If irrigations during the summer and fall have been conducive to rotting and deterioration of the roots, no great benefit can be expected from a single spring irrigation applied just before the danger period.

Effect of Irrigation on Fruit Growth Rate

Huberty (1948) mentioned reports dating back to 1919 in California of observations on the relation between increase in volume of lemon fruits and certain soil-moisture conditions. Since that time, many investigators have attempted to associate the rate at which citrus fruits expand with soil-moisture conditions, seeking a relatively easy means to determine whether or not irrigations are adequate or properly timed. Halma (1934) found that the growth rate of Washington navel oranges decreased in general as the average soil moisture in the top 2 feet of soil decreased; conversely, saturation deficit of the leaves increased as soil moisture decreased.

Furr and Taylor (1939) made an extensive study relating the growth of lemon fruits to the soil-moisture content. They used three different irrigation regimes on each of several orchards having coarse-, medium-, and fine-textured soils.

Table 8–2 defines the treatments and shows the gain in volume over a four- to five-month period for two different fruit sets in each of three orchards. These data show that water may be withheld until the first significant decrease in growth rate without any detriment to ultimate production, except possibly in coarse-textured soil. Obviously one cannot delay irrigation until the fruit growth rate has ceased and still expect to get full growth. The rapid growth after irrigation is insufficient to completely make up the loss that occurs prior to irrigation. Even in coarse-textured soil, which showed the greatest relative reduction for the dry treatment, the average moisture content was above the wilting range all season.

Hilgeman and Van Horn (1954) measured growth of Valencia oranges in Arizona from plots irrigated at two different frequencies over a 2½-month period. One treatment was irrigated on August 29, September 15, October 5, and November 1, and received a total of 8.7 inches of water. The second treatment was irrigated on August 29 and November 1 and received 5.3 inches of water. After each irrigation of the dry plots, a period of rapid fruit growth took place, as can be seen in figure 8–4, but it was not sufficient to overcome the loss that occurred during the dry period. At harvest time, 57 per cent of the crop from the frequently irrigated treatment was size 113 (2.6 inches in diameter) or larger, but only 38 per cent of the crop from the dry treatment attained this size. When insufficient water was present, the trees adjusted to it, reducing water use and fruit growth without observable moisture shortages.

Table 8–2
EFFECT OF IRRIGATION INTERVAL ON LEMON FRUIT GROWTH*

Soil Type	Season	Period Measured	Average Volume Gain Per Fruit (Cc)		
			Wet	Medium	Dry
Coarse	Spring set	June 15–Nov. 18	128.2	106.6	91.0
	Summer set	Aug. 19–Dec. 15	67.5	60.7	54.0
Medium	Winter set	May 17–Sept. 10	106.6	110.3	101.8
	Spring set	Aug. 18–Nov. 20	65.4	66.8	53.6
Fine	Winter set	May 17–Sept 9	97.3	99.9	78.5
	Spring set	Aug. 21–Dec. 15	97.3	97.2	63.1

Source: Adapted from Furr and Taylor (1939).

* Irrigation intervals were as follows:
Wet (short interval)—irrigation water applied at such short intervals that little or no decrease in fruit growth rate occurred as a result of water deficit.
Medium (intermediate intervals)—irrigation water applied at the first significant decrease in fruit growth rate that could be attributed to water deficit.
Dry (long interval)—irrigation water applied when fruit growth had almost or entirely ceased or when trees began to show excessive leaf drop or rolling of the leaves.

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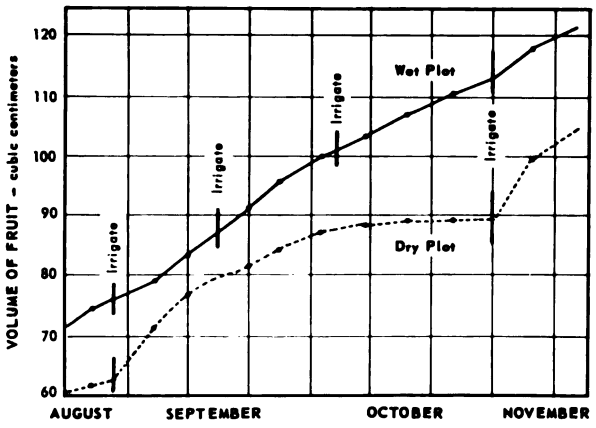

Fig. 8–4. Effect of irrigation on the growth of Valencia oranges. (Hilgeman and Van Horn, 1954. Courtesy of Arizona Agricultural Experiment Station.)

In later work, Hilgeman and Howland (1955) related fruit growth measurements to soil-suction measurements made with tensiometers. In one moderately coarse-textured soil, tensiometers installed at a 30-inch depth showed a soil suction of about 32 cb when the fruit growth rate slowed. In another soil, which was medium-textured, fruit growth rate slowed when the tensiometers showed a soil suction of 50 to 60 cb.

Lombard *et al.* (1965) made fruit growth measurements on navel oranges grown on irrigation plots at Riverside in which treatments were: (1) irrigation when soil suctions of 20 cb were attained at a depth of 20 inches; and (2) irrigation when soil suctions of 100 cb were attained at a depth of 20 inches. In addition to fruit growth, measurements were made of leaf-saturation deficits, air temperature, relative humidity, and average daily wind velocity. A multiple regression analysis showed that soil suction above 20 cb was the main factor influencing fruit growth, presumably because the unsaturated hydraulic conductivity of the soil declines greatly between 20 and 100 cb, so that moisture movement to the roots is restricted. At high soil suction, fruit growth was influenced by vapor pressure humidity of the atmosphere. This emphasizes the importance of maintaining low soil suctions during periods of low humidity.

In a hormone-spray experiment concerned with fruit size of Valencia oranges, Erickson and Richards (1955) combined two spray treatments with two irrigation treatments. The irrigation treatments were: (1) application of water when the average reading of six tensiometers at the 1-foot depth was 30 cb; and (2) application of water when three out of six tensiometers at the 2-foot depth reached 70 cb. The wetter treatment produced more fruit in larger size categories and less in smaller size categories than the dry treatment. The total number of fruits produced under each irrigation treatment was about the same.

A trial relating fruit growth rates to soil-water conditions and air temperature was conducted by Beutel (1964) on both lemons and oranges growing in sandy loam soils. Tensiometers were installed under several trees on which fruit were tagged for measurements. Measurements were made two or three times a week from July through November. Tensiometer readings were grouped into classes of 10 cb each, and growth rates obtained at each measurement were placed with the class of soil suctions existing during the few days that measured growth rate occurred. Results are shown in figure 8–5. There are no plottings for the first two or three days immediately after irrigation when the greatest accelerated growth takes place. Growth rates for lemons decreased as soon as soil suctions exceeded the 30-cb range. With oranges, the growth rate diminished steadily after readings exceeded 10 cb,

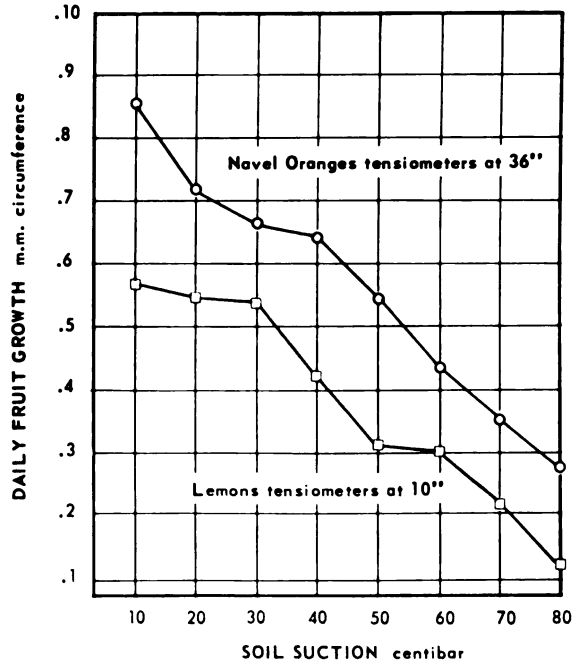

Fig. 8–5. Effect of soil suction on fruit growth rate. Each point plotted represents a 10 cb soil-suction range, 5 cb either side of the plotted point, and the daily growth rate while that range of values existed. The first two or three days after each irrigation are not plotted.

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but this can be attributed to the greater tensiometer depths, where readings are lower than at shallower depths.

At times a slowing of growth rate occurred somewhat out of line with the existing soil suction. It was found that these discrepancies occurred during periods of high air temperature. Therefore, the data were further classified to compare growth rate at various soil suctions within a given class of air temperature ranges. The results are shown in figure 8–6. It is evident that fruit growth responds to an optimum combination of soil-water condition and air temperature, and that the temperature at which growth rate is reduced is lower at high suctions than at low soil suctions.

Fruit growth measurements seem to be sensitive to soil-water changes within the range which a tensiometer measures. Such measurements, therefore, can be a useful adjunct to tensiometer use by helping to establish a range of tensiometer readings which has significance in relation to fruit growth. Correlation of fruit growth and tensiometer readings should only be attempted when trees carry a normal crop.

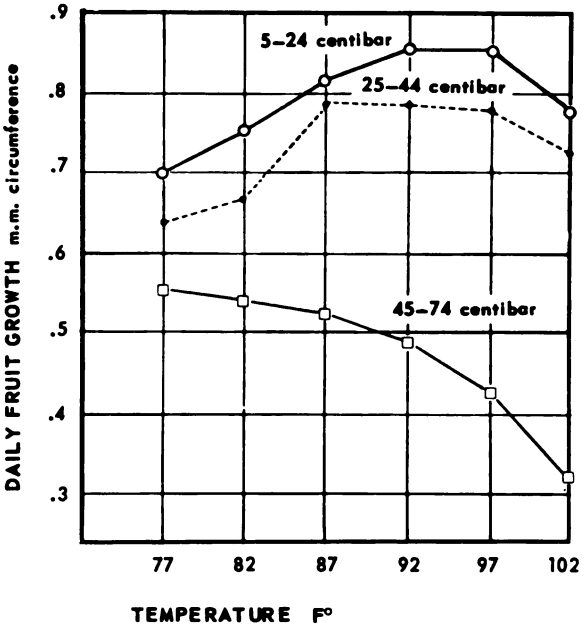

Fig. 8–6. Effect of atmospheric temperature and soil suction on growth rates of navel oranges. Each point is the mean of daily growth rates within a five-degree daily maximum temperature range and within the indicated soil-suction ranges. (From Beutel, 1964.)

Effect of Irrigation on Yield

Some work has been done relating fruit yield to different irrigation treatments. A comparison of fruit yields and ranges of annual water application as made by Taylor (1941) in southern California is presented below.

Water Application Range (Inches per Year)	*Yield Average (Boxes per Tree)*
32–36	4.36
28–32	5.15
24–28	5.21
20–24	4.73
16–20	4.31
12–16	3.32

The main point to be derived from these data is that very low and very high water usages reflect poor irrigation management and are associated with lower yields.

Richards and Huberty (1956) conducted an irrigation experiment in a 10-acre navel orange orchard at the University of California Citrus Research Center, Riverside, on Ramona sandy loam soil. The experiment consisted of duplicate 80-tree plots for each of three irrigation treatments. Two treatments were irrigated at intervals of three weeks and six weeks, representing the extremes practiced in the inland citrus area around Riverside. A third treatment was irrigated when two out of three tensiometers placed in each plot at a depth of 2 feet read higher than 75 cb. The results are shown in table 8–3. Because of annual fluctuations affecting yields from all treatments, the yields are expressed as a percentage of the average yield for the entire 10-acre orchard for the particular year reported. Yields tended to be highest from the treatment irrigated at three-week intervals, which received the greatest number of irrigations and the most water per season. Yields from the tensiometer-regulated plots were slightly but not significantly lower, though the amount of water used was much less. This is because the tensiometer-regulated irrigations permitted longer intervals during the spring and fall of the year, though sometimes shorter intervals in mid-summer than the three-week treatment.

The three- and six-week irrigation intervals were continued through 1956, then divided and switched under Stolzy *et al.* (1963) so that irrigation intervals were based entirely upon soil-suction measurement. Half of the plots previously

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Table 8–3
AMOUNTS OF WATER APPLIED AND FRUIT YIELDS IN A NAVEL ORANGE IRRIGATION EXPERIMENT

Crop Year	Irrigated at 6-Week Intervals		Irrigated at 3-Week Intervals		Tensiometer-Regulated Irrigation†		Average Orchard Yield For All Plots	
	Irrigation (Inches)	Yield° (Per Cent)	Irrigation (Inches)	Yield° (Per Cent)	Irrigation (Inches)	Yield° (Per Cent)	Number of Fruit Per Tree	Pounds of Fruit Per Tree
1950	22.2	70	33.6	123	27.4	96	302	137
1951	23.7	79	27.6	108	25.5	106	492	166
1952	26.0	73	23.8	115	15.9	108	679	212
1953	35.1	115	36.4	116	27.8	97	586	238
1954	24.7	108	31.1	114	18.4	106	.....	.....
Average	26.3	89	30.5	115	21.9	104	515	188

Source: Richards and Huberty (1956).
° Expressed as per cent of average annual yield for 10-acre orchard in which experiment was performed.
† Irrigated when two out of three tensiometers at 24-inch depth reached 75 cb.

on the three-week interval were irrigated for the next three years whenever the soil suction at 20 inches depth reached 20 cb. The other half of the three-week interval plots was irrigated whenever the soil suction at 20 inches depth reached 100 cb. The plots from the previous six-week interval treatment were divided in the same fashion. There were six replications of the 20-cb plots and five replications of the 100-cb plots. Tensiometers placed at 32 inches depth in the 20-cb plots and at 42 inches depth in the 100-cb plots were used to evaluate the amount of irrigation water applied and to insure that there were no excess applications. Avoidance of excess applications is very important when utilizing low-soil-suction irrigation treatments. The results of this revised irrigation experiment are shown in figure 8–7.

When the three-week-interval treatment was switched to 20 cb, the yield, which averaged slightly over 250 pounds per tree during the last

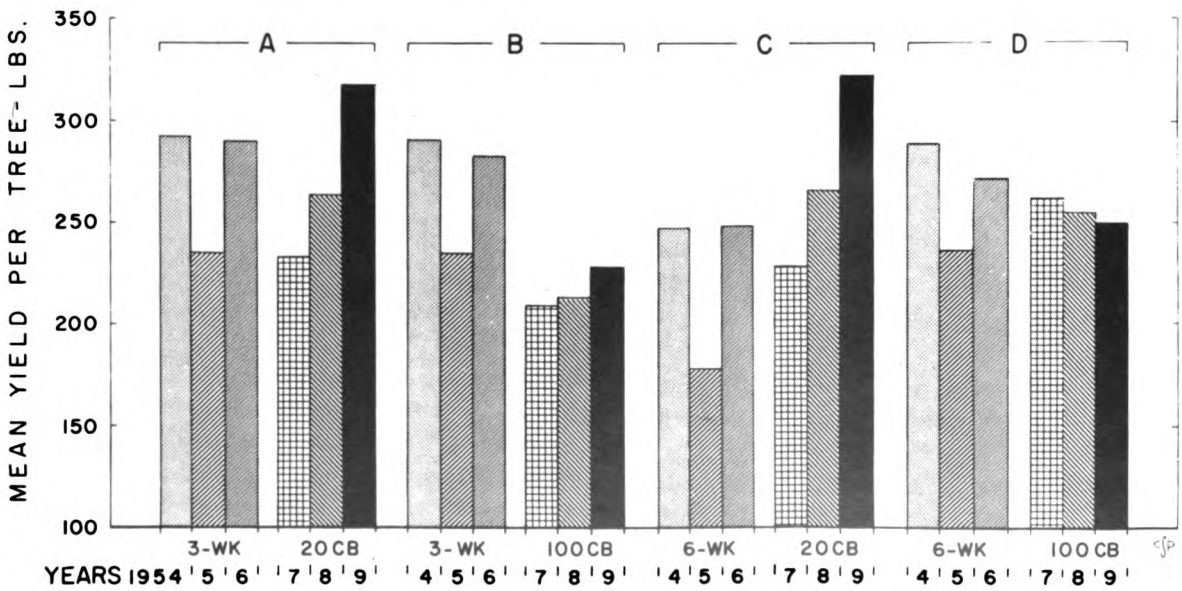

Fig. 8–7. Mean yield of fruit from mature navel orange trees irrigated on the basis of a three- and six-week calendar schedule from 1954 through 1956 and on the basis of soil-suction values from 1957 through 1959. (From Stolzy *et al.*, 1963.)

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three years of the three-week-interval irrigations, gradually increased during the next three-year period, reaching about 320 pounds per tree in 1959 (fig. 8–7, *A*). When the three-week interval was switched to 100 cb, an immediate drop in yield occurred. Yield remained relatively low for the three years with a slight increase to about 225 pounds per tree by the third year (fig. 8–7, *B*). When the six-week interval was changed to 20 cb, the yield started to increase and continued each year, reaching about 330 pounds per tree in 1959 (fig. 8–7, *C*). When the six-week interval was changed to 100 cb, there was no immediate decrease such as occurred when the three-week interval was switched to 100 cb, but there was a gradual reduction over the three-year period to about 250 pounds per tree in 1959 (fig. 8–7, *D*). The experiment showed that the previous irrigation treatments produced considerable effect on the trees, resulting in a strong tendency for them to produce in accordance with past production for at least two years after the change. It should be remembered by those planning to change irrigation practices that it may take two or three years before a tree responds completely to a new environment and about six years before roots adjust (Cahoon *et al.*, 1964).

One of the longest irrigation experiments that has been reported using the same basic treatments was conducted by R. H. Hilgeman at the Arizona Citrus Experiment Station, Tempe. The experiment has been reported progressively by Hilgeman and Van Horn (1954), Hilgeman and Howland (1955), Hilgeman (1956), Hilgeman and Sharples (1957), and Hilgeman and Rodney (1961). The experiment was begun with sixteen-year-old Valencia orange trees on sour orange rootstock, growing in Mohave sandy loam soil. This is a deep calcareous soil in which trees root to a depth of five or six feet, although more than half of the roots are in the top two feet. The experiment consisted of three principal irrigation treatments, which were replicated three times: a wet, a medium, and a dry treatment. Available water was maintained throughout the entire root zone at all times in the wet treatment (except for the upper 4 inches of soil subject to surface evaporation). In the medium treatment, the soil was permitted to dry until its upper foot reached the wilting range. The dry treatment soil was permitted to dry until its upper two feet reached the wilting range. Because of the calcareous nature of the soil, trees on the wet treatment developed iron chlorosis. To counteract such chlorosis, a fourth, mixed treatment was utilized in which trees were grown under the wet schedule between March and July and under the dry schedule for the rest of the year.

Because of climatic variables, yields varied in different years. Average yields over a seven-year period and other data are presented in table 8–4. There was no significant difference in average yield for the wet and medium treatments, but the dry treatment definitely resulted in a lower yield. Trees of the mixed treatment did not develop iron chlorosis and produced the highest yield of all treatments, but the drying period they underwent reduced fruit growth and led to smaller sizes.

The irrigation experiment by Samish (1957), previously discussed and reported in table 8–1 (see p. 239), consisted of three irrigation treatments, which received an average of 10.4, 16.8, and 24.6 inches of irrigation water per year, respectively, and an average of 14 inches of rainfall annually. Total fruit yields for the first five bearing years were 597, 833, and 1,015 pounds per tree for the dry, medium, and wet treatments, respectively. Variability was great, but the difference between the medium and dry treatment was significant and that between the medium and wet treatment was almost significant at the 5 per cent level.

Irrigation experiments in Florida (Koo and Sites, 1955; Koo, 1963) have shown that good irrigation is profitable in both high and low rainfall years. Much of the citrus is grown on deep, fine sand where supplemental irrigation has been practiced by some growers for many years with variable results. The usual procedure has been to irrigate when the trees show stress or wilt, thus obtaining beneficial results from irrigation only in dry years. By irrigating when soil-water measurements showed one-third or two-thirds depletion of the available water in the upper five feet of soil, Koo (1963) obtained significant yield increases in both wet and dry years for grapefruit and three varieties of oranges (table 8–5). The most economic treatment was irrigation at one-third depletion from January through June, the period when droughts generally occur as well as blossom and fruit set, and at two-thirds depletion from July through December. An exception might occur when irrigation costs are high and fruit prices low. Then irrigation at two-thirds depletion all year may be more economical, though total yields will be less.

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Table 8–4
EFFECT OF SOIL MOISTURE ON VALENCIA ORANGE TREE GROWTH AND SIZE, QUALITY, AND YIELD OF FRUIT*

Irrigation Data and Tree Response	Irrigation Treatments				L.S.D. at 5%
	Wet	Medium	Dry	Mixed	
Irrigations (number/year)	15	10	5	9	.....
Water applied (inches)	65	50	35	49	.....
Soil suction at 30 inches before irrigation (cb)	30	50	70†	....‡	.....
Available water depletion in upper two feet of soil (per cent)	55	70	95	55/95	.....
Trunk growth (cm^2/year)	19	16	12	15	2.6
Yield (fruit/tree)	677	680	561	743	109
Fruit of size 113 and larger	62	60	55	44	11
Soluble solid (per cent)	11.8	12.2	12.8	13.2	0.66
Peel thickness (mm)	4.6	4.5	4.9	5.0	0.34
Ascorbic acid (mgm/100 ml)	49	50	53	52	3.4

Source: Hilgeman and Rodney (1961); reprinted with permission of Arizona Agricultural Experiment Station.

* Average of seven years.

† Above 70 cb before each irrigation for three to six days in winter and 10 to 14 days in summer.

‡ Irrigated on wet schedule from March to July, dry schedule from August to February.

DETERMINING IRRIGATION TIMING AND AMOUNT OF WATER

Good irrigation consists of three basic elements: correct timing of applications, supplying the proper amount of water, and distributing water uniformly.

Irrigation experiments such as those reviewed in the preceding section provide knowledge of the effects of underirrigation, overirrigation, and good irrigation on root development and health, top growth, fruit growth, and yield under various soil and climatic conditions. The water-plant relationships demonstrated by such experiments are important and should be used by the citrus grower as a basis for determining his irrigation-management practices. Such experiments, however, do not tell him the exact timing of irrigation and amount of irrigation water that will be needed in any particular month or year to meet his specific conditions. His requirements must take into account such factors as local climatic conditions, the type of soil, and the age and vigor of his trees. Various means are employed to translate the knowledge obtained from irrigation experiments into grower practices involving timing of irrigation and determination of the proper amount of water.

Localized studies of water requirements such as that of Pillsbury *et al.* (1944) provide information on the amount of water needed by citrus in the areas studied. Figure 8–8 shows the water requirements by months for the interior basin of southern California. Water requirement data such as these are useful primarily for engineering purposes (see p. 275), but are not particularly useful in determining the irrigation needs of an individual orchard, except to inform the grower that his trees will use three times as much water in summer as in winter. Such data do not take into account differences in root depth and storage capacity of the soil in an individual field or differences in tree vigor and climatic deviations from the normal.

Calendar Schedule

Probably the most commonly used method for determining time of irrigation and the amount of water needed is the calendar schedule. This is

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Table 8–5
EFFECTS OF IRRIGATION ON YIELD OF GRAPEFRUIT AND ORANGES IN FLORIDA

Year*	Irrigation Treatment	Fruit Yield (Pounds per Tree)			
		Marsh Grapefruit	Oranges		
			Hamlin	Pineapple	Valencia
1960	No irrigation	652	595	530	446
	Low†	875	653	605	525
	High-low‡	815	750	591	570
	High§	1,092	740	616	555
1961	No irrigation	853	658	555	509
	Low	1,301	955	643	719
	High-low	1,351	1,105	620	775
	High	1,350	1,070	685	890
1962	No irrigation	1,140	925	690	504
	Low	1,300	1,020	750	550
	High-low	1,520	1,200	826	630
	High	1,575	1,260	835	582
L.S.D.					
	At 5 per cent	94	80	62	62
	At 1 per cent	130	109	....	85

Source: Adapted from Koo (1963).
* Rainfall for 1960, 69.2 inches; 1961, 37.9 inches; 1962, 43.6 inches.
† Low: irrigated when two-thirds available soil water depleted from upper 5 feet.
‡ High-low: irrigated from January to June when one-third available soil water depleted from upper 5 feet, and from July to December when two-thirds available soil water depleted from upper 5 feet.
§ High: irrigated when one-third available soil water depleted from upper 5 feet.

usually established by the water supply organization on the basis of studies it has made of water requirements and soil-storage capacities in the area served. The schedule is usually set up by officers of the water supply agency during the winter period and may be modified each year to reflect differences in need brought to attention by the water users. Usually, schedules continue much the same year after year and are fairly rigid because of the requirements of the water organization to deliver water to all growers in the service area. Schedules commence with the beginning of the irrigation season in the spring and remain fairly constant until irrigation is no longer needed in the fall. Growers generally have the option of passing up their irrigation turn in the spring or fall, if they think it is not needed. Growers who have their own individual water supply or water available whenever they need it, frequently set up their own calendar schedule and irrigate by it throughout the irrigation season.

Irrigation by calendar schedule is the easiest method of irrigation management. The schedule can be established well in advance, and other cultural operations can be planned so that they will not conflict with irrigation dates. Because it has been the traditional method, most growers have not opposed the calendar schedule system or attempted to influence the water supply agency to provide water on a different basis.

Scheduling irrigation by the calendar method has several defects which growers increasingly recognize. Figure 8–8 shows that less water is needed in the spring and fall than during the summer. Figure 8–9 shows that a greatly different frequency of irrigation is required to meet these varying needs. The principal weakness in most calendar schedules is that water is supplied too frequently and in too great an amount in the spring, possibly not frequently enough during the peak use months of summer, and again too frequently during the fall months. Since the schedule is usually designed to come closest to meeting the needs of summer months, spring and fall months generally are times of excessive irrigation. On all but deep, rapidly draining, open

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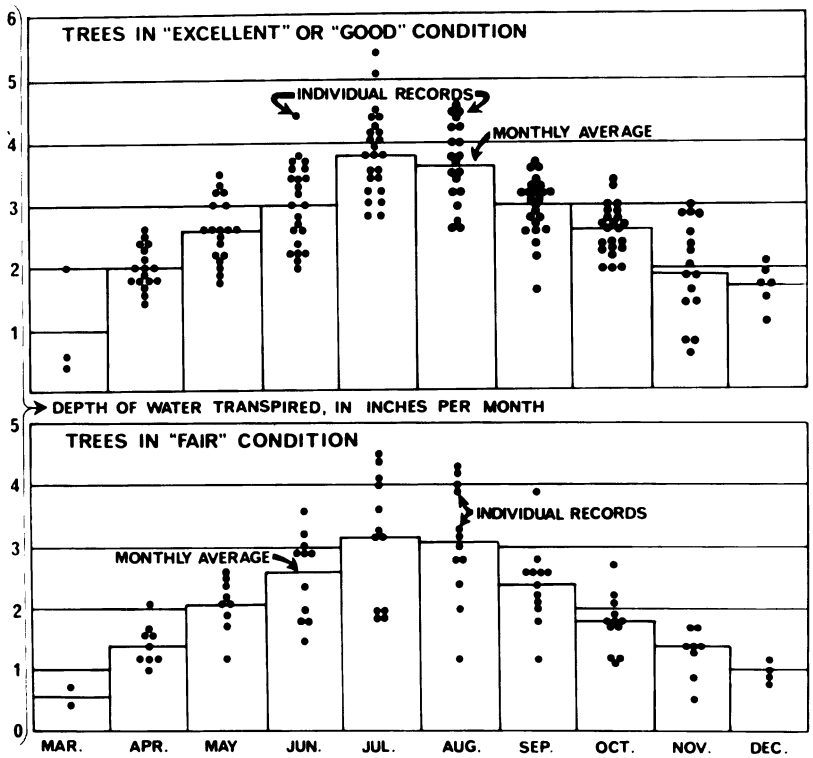

Fig. 8–8. Distribution of individual monthly and average monthly transpiration records, Riverside and San Bernardino Counties, California, 1930–35. (After Pillsbury, Compton, and Picker, 1944.)

soils, excessive irrigations are detrimental in the spring months, but the grower is usually reluctant to pass up his turn. A hot spell arriving earlier than usual can prove serious if it catches the grower during the fruit-set period with his available soil water more than half depleted. For this reason, most growers fear passing up a regular turn in the spring. They therefore apply water even though they realize it is not needed and may contribute to root deterioration. The rigid calendar schedule system of irrigation is detrimental to good citrus production and should be modified to provide more flexibility.

Application According to Need

To obtain the best response, irrigation water should be applied to the individual field or section of a field according to the needs of trees growing thereon. If a grower has his own water source or if water is available from the irrigation supply agency on demand or on a fairly flexible basis, he is in a position to irrigate according to the need of his trees, both as to timing and amount of water. Several means have been proposed for determining the irrigation needs of citrus trees.

Visible Symptoms.—Probably the simplest means of determining irrigation needs of trees from the standpoint of effort expended is to examine the trees for visible symptoms. Furr and Taylor (1939) observed the curling of immature leaves on succulent, elongated shoots as the first visible sign of stress. Cessation of shoot elongation occurred about the same time. Later, young leaves showed severe distortion in shape and old leaves began to drop. Citrus experts have expressed various reactions to the method of determining irrigation needs by visible tree symptoms. Because of the variabilities always encountered in soil-water measurements, Samish (1957) stated that reliance on tree appearance as an indicator of irrigation need is the better approach for the horticulturist. Koo (1963) reported that the practice common to Florida of waiting to irrigate until trees show a visible stress is uneconomic, while properly timed irrigation is profitable. Furr and Taylor (1939) stated that their experiments estab-

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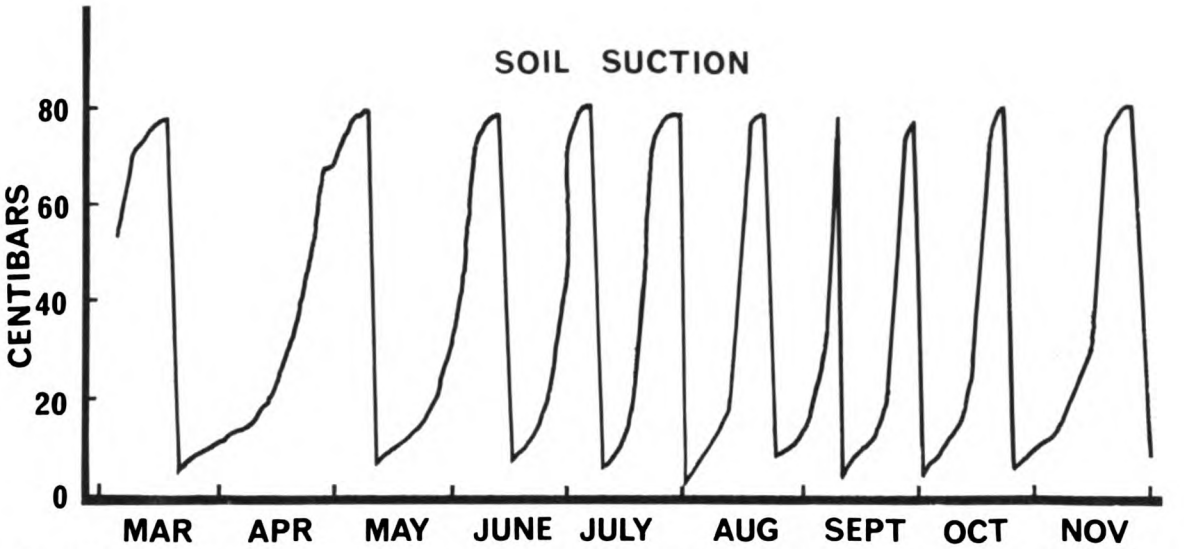

Fig. 8–9. A tensiometer record used to schedule irrigations. Irrigations were applied throughout the year when tensiometers at 18 inches depth near an inner furrow of a mature orchard reached 70 cb. Intervals vary from 20 to 52 days during the growing season. (Richards and Hagan, 1958.)

lished the fact that reduced growth and abnormal loss of leaves resulted when lemon trees were allowed to go without irrigation until signs of water shortage were clearly evident. Lyon (1958) noted that a tree on sweet orange rootstock shows stress earlier than on other stocks, and an early sign of stress is retardation of fruit growth; slowing of shoot growth comes later and is not as useful an indication of water need.

Fruit Growth Rates.—Another plant response which can be used to indicate the need of the tree for water is fruit growth rate. The use of this response by a number of investigators in their research was described in some detail in the previous section. Fruit growth rate cannot be observed and must be measured. Measurements must be made frequently and records kept if the method is to prove useful. This requires considerably more work than simple tree observation, but appears to be a much more satisfactory means for determining the true needs of the trees for water since it reveals a water deficiency before visible symptoms occur.

If fruit growth records are to be used as a guide for irrigation, five to ten fruits per tree on several trees distributed through the orchard must be tagged and measured regularly. Measurements should be made at the same time of day, preferably from 7 to 9 A.M. A steel tape measure is generally used to measure fruit circumference. The measurements should be averaged and plotted on a chart as in figure 8–4 (see p. 242), with fruit size represented by the vertical axis and the time or date by the horizontal axis. If the ascending line starts to curve towards a more nearly horizontal line, the fruit growth is slowing. If the line becomes horizontal, fruit growth has ceased. If the line turns downward slightly, the fruit is actually shrinking. According to Furr and Taylor (1939), if water is applied soon after the first significant decrease in growth rate, the ultimate size of the fruit will not be reduced because the growth rate accelerates for a few days after irrigation. If water is withheld until the growth rate ceases, however, the final size of fruit is reduced and the trees may even lose some leaves. To avoid the dangers of over-irrigation, they feel it advisable to withhold water until a decrease in growth rate of fruit occurs and not to irrigate as long as the line is progressing steadily upward. Oppenheimer and Elza (1941) pointed out that fruit growth rates are of little use before July, but are mainly useful between July and December.

Climatic Methods.—Reeve and Furr (1941) proposed another means for determining irrigation need. They felt that an easy-to-perform single-valued measure integrating the effects of solar radiation, air temperature, relative humidity,

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and wind on transpiration was needed, and proposed that this need be met by measuring evaporation. Black-pan evaporimeter data were obtained and used in predicting moisture use from the soil. For use in any specific location, a coefficient must be worked out by extensive sampling to compare with the black-pan evaporation data. This method has not achieved general use. The Penman (1950) formula, however, using the several climatic measurements mentioned above and a crop resistance factor is widely utilized by the British on various crops. This factor is variable and should be calibrated.

An examination of the crop resistance factor for citrus has been presented by Van Bavel, Newman, and Hilgeman (1966). They show a high resistance to water loss which results in annual evapotranspiration from citrus of only about one-half the potential evaporation. The resistance factor varies seasonally by a ratio greater than 2 to 1, mainly as a function of the age of leaves. Young leaves, which predominate after the growth flushes, have a much lower resistance than old leaves, and lose water more rapidly. This variable and relatively little known resistance factor is a present obstacle to the use of climatic measurements for the purpose of scheduling irrigations.

Another possible reason why the climatic method has not proved generally useful for citrus may be related to the findings of Richards, Weeks, and Erickson (1961). They grew lemon trees in potted soil under various degrees of artificial compaction. All trees were exposed to the same climatic environment. Pots were individually irrigated to maintain soil-suction values between 5 and 60 cb. Tree growth and water use varied with good correlation between them. Tree growth variation bore no relation to soil bulk density and was presumed to be caused by vigor and health variations among the individual trees. Seedlings planted in containers of 3 feet diameter and 4 feet depth in early 1956 had a water use ranging from 32 to 46 inches in 1957, and from 39 to 98 inches in 1958. This variability in water use under uniform climatic conditions raises questions about the effectiveness of basing irrigation programs for citrus on climatic evaluation alone, unless the method is combined with some means for soil-water evaluation.

Soil-Water Depletion.—Determination of the amount of water in the soil by taking soil samples from various depths in the root zone (see p. 232) has been used by many investigators as a guide for timing irrigation and establishing the amount of water needed ever since irrigation research was initiated. When the soil-water content is related to field capacity and wilting point (see p. 231), the relative wetness or available water content of the soil is obtained. Most of the research previously cited indicated that apparent fruit growth rate slowed or ceased before the soil reached the wilting range in any appreciable fraction of the root zone and that the degree to which the soil can be allowed to approach the wilting range is dependent upon the climatic environment, the soil texture, and the rooting characteristics, including depth and density. Furr and Taylor (1939) felt that measurement of soil water is not a very reliable index of the needs of the tree for water, mainly because of wide variability in root density. However, they reported that results from their plot studies show quite clearly that before the moisture content of all the soil in even the principal root zone was reduced to the wilting range, growth rate and total growth of fruit for the season were greatly reduced.

Obtaining sufficient soil samples for reliable data is a laborious process, and requires laboratory facilities to dry and weigh the samples. For these reasons, it is seldom attempted by commercial growers, though some have employed consultants associated with commercial laboratories to make determinations from soil samples. An easier measurement of soil water called the neutron method, described on page 233, has been employed by research people, but has limitations for use by growers.

While it can be assumed that few growers will measure water by the soil sampling or neutron techniques, there remains the opportunity for all growers to examine the soil with a soil auger, soil tube, or probe, thus obtaining approximate indications of the water status. If this were done on a reasonably frequent basis so that the grower became familiar with the appearance and feel of his soil at different water conditions, and if the results were calibrated with fruit growth rates or other performance characteristics, a fairly good criterion would be available to the grower on which to base an irrigation program as far as timing is concerned. With suitable probing and observation shortly after an irrigation, he could also learn with reasonable satisfaction whether or not the amount of water applied had been adequate, too little, or too much. Since this operation is fairly laborious, it is likely to be neglected, especially in hot weather.

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Determining irrigation need by use of instruments to measure the soil-water condition has gained favor with many citrus growers and research and advisory people. A properly placed tensiometer keeping day-by-day track of the changes in soil-water condition at different positions in the root zone combines essentially all of the elements that bear upon the use of water by the trees, and meets the ideal of a single-valued measurement desired by Reeve and Furr (1941). Tensiometer measurements register the soil-water condition wherever they are placed in the root zone. When correlated with tree performance, tensiometer measurements serve as a guide in determining timing of irrigation and amount of water needed.

Several investigators have suggested that measurement of soil water is not a very reliable index to the water needs of the tree, mainly because of wide variability in soils and root density (Furr and Taylor, 1939). There is much variation in citrus root density and water withdrawal rates at various points within a citrus orchard, both horizontally and vertically. Work with tensiometers has helped clarify this variation and reveal locations where tensiometers can be placed to follow satisfactorily the withdrawal of moisture by the tree roots and also the replacement of water by an irrigation.

Richards and Huberty (1956) placed tensiometers at a 2-foot depth just inside the furrow nearest the tree. Hilgeman and Howland (1955) reported the use of tensiometers installed at the northeast corner of the tree at a depth of 30 inches. Stolzy *et al.* (1960) discussed the placement of tensiometers in commercial citrus groves at two depths, usually 12 to 18 inches for the shallow depth and 24 to 36 inches for the deeper depth. Tensiometers were generally installed at the southwest corner of the tree just inside of the tree furrow (fig. 8–10). Charts made from tensiometer readings revealed much about the nature of the irrigation programs used in the orchards studied, and the apparent effect of these programs on root density and distribution (fig. 8–11).

Placement of tensiometers at two depths has become quite common. Hammond (1956) used tensiometers at one- and two-foot depths while Stolzy *et al.* (1963) used tensiometers at depths of 20 and 32 inches in the wet plots of their irrigation experiment and at 20 and 42 inches in the drier plots. It is generally recommended that the shallower tensiometer be installed within the zone of maximum root density at about one-third

Fig. 8–10. Tensiometer location in a mature citrus orchard. Just inside the inner furrow at southwest corner of the tree.

of the linear depth of the principal root zone. The deeper instrument should be installed below the zone of maximum root concentration at about twice the depth of the shallow instrument, situating it at about two-thirds to three-fourths of the depth of the principal root zone.

The lateral position and distance from the tree of a tensiometer installation should be chosen so that it is in a reasonably concentrated root location, one from which water will be withdrawn readily between irrigations and to which the water will move readily during irrigation. Care is needed in sprinkler-irrigated orchards to place tensiometers where water from the sprinkler can reach the instrument directly. The foliage should neither shield the instrument from the sprinkler water nor concentrate water on the instrument. Experience in California has shown that the southwest corner of the tree dries most rapidly and the northeast corner the least rapidly. Generally, tensiometers, are installed at the southwest corner to indicate irrigation need before there is any opportunity for the tree to become stressed. In some situations, the soil tends to remain too wet, and it is considered prudent to allow the soil to become drier. This can be accomplished by installing tensiometers at the northeast corner of the tree. Installing tensiometers deeper in the less dense part of the root system also permits greater drying of the soil in the major root zone before tensiometers exceed their reading limit.

Once tensiometers are installed, a record should be kept of their readings at periodic intervals and the data obtained should be plotted as in

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figures 8–9, 8–11, 8–12. An orchard should be divided so that sections having known differences of soil or trees can be irrigated separately. (Some effort should be made to learn soil or tree differences.) Two or more instrument locations should be established in each section. Irrigation of each section on the basis of average instrument readings will come as close to meeting variable needs of trees as any method now available.

Hilgeman and Howland (1955) describe the correlation of tensiometer measurements with fruit growth rate. After several irrigation cycles, a comparison of fruit growth rates with tensiometer readings reveals soil-suction values at the particular depths being measured at which an appreciable reduction in apparent growth rate takes place. In the example cited, Hilgeman and Howland showed that appreciable fruit growth reduction occurred when tensiometers installed at a 30-inch depth attained a reading of approximately 50 cb. Beutel (1964) showed that fruit growth rate for lemons had declined nearly 50 per cent when the soil suction value at 10 inches depth reached 50 cb. With oranges the growth rate had declined 50 per cent when the soil suction at 36 inches depth reached 60 cb (see fig. 8–5, p. 242).

The use of soil-suction measurements for determining time of irrigation and amount of water needed is described in some detail by Richards and Marsh (1961). The rate at which soil-water conditions change can be observed from tensiometer charts and is valuable in planning for the next irrigation. For advance planning, the rate of change is frequently more significant than an individual reading. Readings also may be correlated with tree performance. After suitable correlation, the measurements at the shallower depth are used in determining when to irrigate. The irrigator often does not have reliable information about the amount of water he is applying, but knows with reasonable accuracy how long he has applied water. Twenty-four hours after completion of an irrigation, the response obtained on the tensiometers is noted. By this time most of the rapid downward penetration of water has occurred and the readings reveal whether penetration has been sufficient to wet the entire root zone. If the root zone was not entirely wetted, the irrigator has learned that he should have run water for a somewhat longer time and can make this correction at a subsequent irrigation. If the readings are lower than 5 cb after an irrigation, it can be assumed that more water was received than necessary, and the irrigator can run the water for a shorter length of time at subsequent irrigations.

There may be times when the grower does not desire to thoroughly rewet the entire root zone each time he irrigates. In Florida, Koo (1961) found that oranges removed water from the top 78 inches and grapefruit from the top 90 inches of a Lakeland fine sand at Lake Alfred, where a clay layer occurs at a depth of 96 inches. However, 90 per cent of the removal occurred in the upper 42 inches of soil for oranges and the upper 54 inches for grapefruit. Hilgeman and Van Horn (1954), working with a soil having a root zone nearly 6

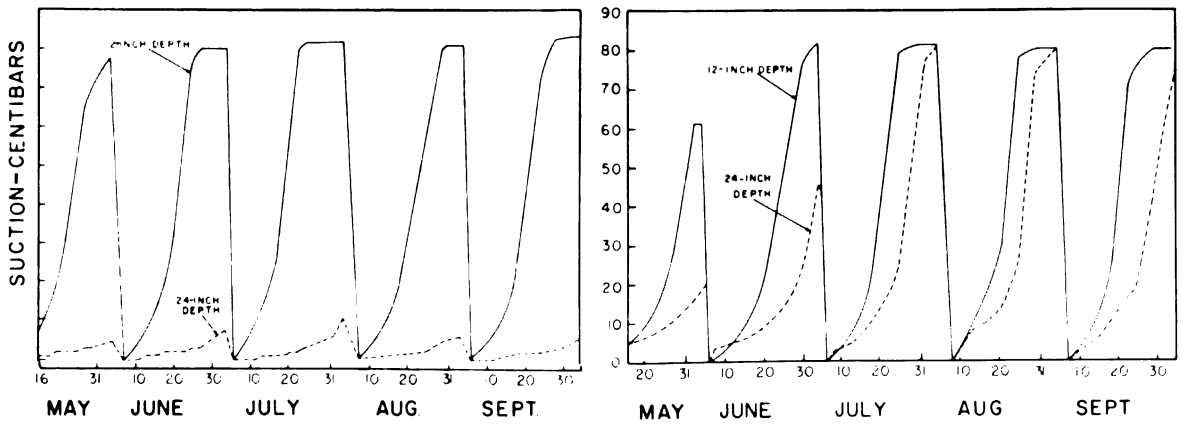

Fig. 8–11. Tensiometer records from a mature citrus grove on Ramona loam soil, furrow-irrigated monthly for a three-day period. Tensiometers were installed at the drip line just inside the tree furrow on the southwest side of the tree. Left: the third tree in a 36-tree run. Root density at 2-foot depth is sparse and moisture condition remains very wet, even though it becomes quite dry at the 12-inch depth after 15 or 20 days. Right: the thirty-third tree in the 36-tree run. More water withdrawn at the 24-inch depth indicates greater concentration of healthy roots, presumably from less excessive moisture conditions. (From Stolzy *et al.*, 1960.)

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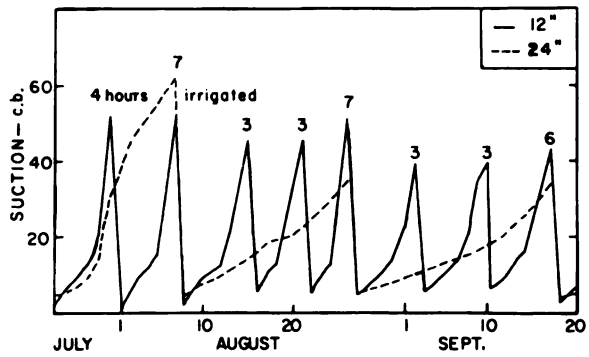

Fig. 8–12. Soil-suction data copied from a grower's record. He used these data to regulate both timing and amount of irrigation. Care was taken to wet the 2-foot depth only at each third irrigation. (From Richards and Marsh, 1961.)

feet deep, stated that it is not necessary to irrigate to the same depth at each irrigation because more than twice as much water is used from the upper two feet as from the third through the sixth foot. They suggest that a heavy irrigation penetrating to a depth of 6 feet could be followed by a light irrigation which penetrates to only 2 feet.

Richards and Marsh (1961) present a chart taken from tensiometer records of a commercial grower who practiced alternate depth of irrigation and used his records for complete guidance as to timing and amount of application (fig. 8–12). A 3-hour irrigation was applied with the sprinkler system each time the tensiometers at 12 inches in depth approached a reading of 50 cb. The irrigation wet the top foot or more of soil, but did not penetrate to the instruments at 2 feet. When readings showed that soil at both depths had dried, a 7-hour irrigation was applied. The longer irrigation was adequate to wet both depths and presumably the entire root zone, since in this case the root zone was about 30 to 36 inches deep. This demonstrates the facility with which both the suitable timing of irrigation and amount of water needed can be learned from the proper charting of tensiometer readings.

The usefulness of soil-suction measurements will increase as more research workers in irrigation and related fields of plant research report their soil-water measurements in terms of soil suction. Mendel (1945) was early in commenting that research workers should publish soil-suction rather than soil-water measurements. Soil-suction measurements are more easily interpreted and applied by the grower.

WATER SUPPLY

Before developing a citrus orchard in any area where irrigation is needed, a citrus grower must determine certain facts about the potential irrigation water supply. The longtime success of his citrus development will depend greatly upon a satisfactory water supply. The important points he must know about the water supply are its chemical quality, cost, adequacy, and availability throughout the season.

Source of Water

The supply of water may come from an irrigation district, a mutual water company, a lake, privately owned wells, or a private reservoir. In the United States, an irrigation district is a tax-levying political subdivision organized to obtain and deliver a supply of water to users within the district. The district may develop its own water by pumping from wells or by impounding surface waters. It may also purchase water by contract from a larger water-distributing organization, which in turn may be organized as a political subdivision or as an administrative branch of federal or state government. An adequate water supply is usually assured in such a district, although prolonged drought may occasionally limit water use for part of a season.

Mutual water companies are business organizations of water users who have pooled their resources to develop a private water supply for delivery to members of the group. Because most of them have early water rights and a system that was developed early with relatively short distribution lines, such companies usually have a dependable water supply which is delivered at a reasonable cost.

If the individual grower is fortunate, he may be able to develop his own well or reservoir on a stream. The supply may be variable, depending upon the nature of the source, competition for the same supply, and climatic cycles which affect renewal of the supply. Usually private sources provide the cheapest water, but the quality may be extremely variable from one location to another.

Cost of Water

Next to having an adequate supply, the cost of water is usually of greatest concern. Cost usually depends upon the distance between the point of irrigation and the source of water. When the source is near the point of irrigation, the cost

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generally will be quite low, but the cost increases as the distance between the source and point of irrigation increases. The cost of water supplied to a farm by an irrigation district or a mutual water company includes the cost of storage of the water, if storage is necessary, the cost of transmission of the water from the source to the farm or field where it is to be used, and the distribution of water within the field. The grower usually pays the cost of developing and transporting the water to some point on his farm in the form of a charge made by the organization delivering the water. In addition, he pays his own cost of distributing the water within his field.

The cost of water delivered to the field varies widely in California, being much lower in the older developments than in the more recent, and much higher for some of the water imported from a distance than for locally developed water. In 1965, growers paid as little as $2.25 per acre foot for water on some government-constructed and district-operated projects, and as much as $50 in some of the more recently developed areas which used pipe-delivered, imported water transported a distance of several hundred miles. It is anticipated that future water supplies imported by new projects from long distances may cost $75 or more per acre foot. In general, much of the citrus acreage developed in California prior to 1950 pays in the range of $10 to $25 per acre foot. Upland developments have higher water costs than valley developments, and one of the results of urbanization in California has been to force citrus acreage from the older valley locations into the upland areas.

In Florida, local development of water by pumping from lakes or wells is common. Where agencies supply water for surface irrigation in the flat-lands, the cost ranges up to $25 per acre without metering. In the Ridge area, water supplied by commercial service organizations to a grove ranges from $20 to $27 per acre foot, delivered under pressure.

For those pumping irrigation water from their own private well, the cost depends primarily on the depth to which the well had to be drilled and the depth from which water has to be pumped. Water cost figures developed by the University of California Agricultural Extension Service in various areas show that total pumping costs using electric motors range from $2 to $20 per acre foot. There are many variables of equipment and conditions affecting costs and sometimes these combine to make costs greater than $20 per acre foot. The main causes of high costs are oversized pumps, having relatively few hours of operation per year, poor mechanical efficiency, and high lifts. Properly designed and maintained systems with lifts not exceeding 200 feet should have total pumping costs ranging from $5 to $10 per acre foot. Extra lift to provide pressure for sprinklers and friction losses in pipelines will add to the pumping cost.

Quality of Water[2]

The chemical quality of water is very important in the irrigation of citrus because citrus is more sensitive to dissolved salts than most plants. Surface streams usually provide reasonably good quality water if the point of diversion is upstream from the zone of general agricultural usage. Streams flowing through arid areas accumulate drainage and return flow from irrigated land and cities, which causes an increase in salinity. Such a progressive increase in salinity is illustrated by table 8–6 which shows the quality of water from the Santa Ana River in southern California at successive downstream stages within a distance of about 43 miles after it emerges from the mountains.

The quality of water obtained from wells covers a wide range. Wells tapping aquifers that are generally replenished annually by water flowing from mountain streams are usually of excellent quality. Wells pumping from aquifers replenished by water slowly migrating from distant sources through various types of underground mineral material may frequently be high in total dissolved salt or in certain mineral ingredients which may be harmful to growing plants, particularly citrus.

Evaluation of the chemical quality of water to determine its suitability for use in irrigating citrus depends primarily on the analysis of total dissolved salts, and the concentration of chloride, sodium, boron, and possibly lithium. Standards for water based on content of these salts are not precise because the effect of the water on citrus depends not only on its mineral content, but also on the type of rootstock used, the nature of the soil being irrigated, the type of irrigation management practiced, and the climate. If soils are porous and free draining, a higher level of salinity in the water can be tolerated without

[2] This section was developed with the cooperation of Dr. R. L. Branson, Extension Soils and Water Specialist, Agricultural Extension Service, University of California, Riverside.

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Table 8–6
SALT CONTENT OF THE SANTA ANA RIVER AT SUCCESSIVE DOWNSTREAM STAGES*

Location	Distance Downstream (Miles)	EC × 10⁶**	Boron (ppm)	Sodium (Per cent)	Milligram Equivalents per Liter					
					Bicarbonate (HCO_3)	Chloride (Cl)	Sulfate (SO_4)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)
N.E. of Mentone (upper canyon mouth)	0	220	.03	25	2.20	0.14	0.21	1.25	0.92	0.74
Waterman Ave. bridge (above San Bernardino)	11	523	.17	27	3.84	0.62	1.09	3.05	1.33	1.61
Rubidoux bridge (above Riverside)	21	615	.20	25	4.45	1.16	2.10	4.20	1.42	1.91
Pedley bridge (below Riverside)	26	892	.12	35	3.36	2.51	4.72	4.20	2.25	3.48
Orange County line	43	973	.16	46	3.59	3.46	4.07	4.30	1.08	4.60

Source: Coe and Florian (1957).
* Samples taken 1948 to 1953.
** Electrical conductivity in micromhos per centimeter at 25° C.

damage to citrus than if soils are slowly permeable and poorly drained. Also, the concentration of salts in the irrigation water that can be used without damage to citrus can be greater if water is abundantly used than if it is scantily used (assuming good drainage), or if the area is subject to sufficient rainfall during part of the year to leach out the salt.

Table 8–7 presents standards for irrigation water used on citrus. This table was developed from reported and observed information on the use of waters of varying quality and incorporates the most recent thinking of scientists working directly on the problem. Some growers may have used water of poorer quality than the ranges recommended in the table without serious detriment or at least without disastrous effects. Standards were developed for the general conditions likely to face citrus growers and not for the unusally favorable conditions which sometimes occur. The standards apply to waters for surface irrigation. A special interpretation is needed for waters used with sprinkler irrigation (see p. 266).

Sodium in irrigation water is evaluated for its effect on the exchangeable sodium of soil. Citrus is unusually sensitive to the exchangeable sodium percentage (ESP) of the soil being adversely affected if the ESP exceeds 6 or 7 (Martin, Harding, and Garber, 1961; Pearson and Huberty, 1959). This is much lower than levels causing soil structure deterioration. The sodium adsorption ratio (SAR) provides an estimate of the ESP that will be attained in soil at equilibrium with the irrigation water (U. S. Salinity Laboratory Staff, 1954). Waters having SAR values of less than 4 are not likely to create an excess of exchangeable sodium in the soil. Waters having SAR greater than 8 are almost certain eventually to produce an ESP injurious to citrus. Irrigation waters having SAR between 4 and 8 may or may not result in an excess of exchangeable sodium in the soil.

Examples of some waters used for irrigation of citrus are given in table 8–8. Salty waters such as those from the Santa Clara River are sometimes used for irrigation of citrus by mixing them with waters of higher quality obtained from a different source or by irrigating alternately with waters from different sources so that the inferior water is not used exclusively or continuously.

Delivery of Water

There are various ways in which water is delivered to a citrus orchard. It may arrive by

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Table 8–7
QUALITY STANDARDS FOR IRRIGATION WATER

Rating of Water	EC × 10³•	SAR†	Chloride		Boron‡
			(Meq/L)	(Ppm)	(Ppm)
Suitable under most conditions, less than—	0.75	4	4	140	0.5
Suitable under some conditions	0.75–2	4–8	4–10	140–350	0.5–1.0
Unsuitable under most§ conditions	2+	8+	10+	350+	1+

• Total concentration of soluble salts in ppm may be approximated if multiplied by 640.

†SAR = sodium absorption ratio = $Na+/\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}$

All ions expressed in milliequivalents per liter. U. S. Salinity Laboratory Staff (1954).

‡ Wilcox, L. V. (1955)
Eaton, F. M. (1944)

§ If any of these figures is exceeded, the water is unsuitable.

Table 8–8
ANALYSES OF SOME WATERS USED FOR CITRUS IRRIGATION

Source of Water	EC × 10³	Dissolved Salts (Ppm)	Chloride (Meq/L)	Chloride (Ppm)	SAR	Boron (Ppm)
Colorado River, Yuma, Arizona•	1.05	700	2.37	84	2.4	0.15
Santa Clara River, Piru, California†	3.65	2,340	4.4	156	5.1	0.9
Gage Canal, Riverside, California	0.51	339	0.65	23	0.9	0.15
Friant-Kern Canal, Terra Bella, Calif.	0.05	32	0.1	4	0.5	0.03
Salt River, Arizona	1.09	611	6.57	233	4.9	0.15
Rio Grande, Texas‡	1.9	1,215	8.0	284	4.1	0.45
Florida wells, inland§	.....	194	0.2	8	1.5	.....
Florida wells, coastal§	.....	2,580	36.2	1,283	60	.....
Nile River, (low) Cairo¶	.....	191	0.46	16.4	1	0.2
Typical good water, Israel‖	0.7	.....	2.4	.....	1.2	.....
Typical poor water, Israel	1.5	.....	10.0	.....	6.3	.....
Lake Apopka, inland Florida••	.....	129	0.48	17	0.5	.....
St. Lucie Canal (Lake Okeechobee), coastal Florida••	.....	305	1.41	50	0.8	.....

• Used extensively for citrus in both Arizona and California.
† Water such as this must be mixed with better water.
‡ Cooper and Shulla (1953).
§ Wander and Reitz (1951).
¶ Ball (1952), p. 111.
‖ Nir (1964).
•• Black and Brown (1951).

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gravity in an open ditch or conduit from which it is diverted to a distribution system in the orchard, or it may arrive in pipelines under either low or high pressure. Low pressure systems are primarily used for surface irrigation, while high pressure systems are generally used for sprinkling. The low pressure and open-ditch systems can also be used for sprinkling by installing a booster pump and suitable filtration apparatus.

Methods of delivery are classed as rotation, demand, and continuous. Under the rotation system, a fairly large flow of water is available to the grower for a given number of hours on a set calendar date, which is usually determined in advance of the irrigation season. Rotation systems of delivery are the most efficient from the standpoint of the water delivery agency. They make it possible to deliver a high volume flow consistently to a large number of growers with a minimum of delivery capacity in the canal or pipelines. The rotation system is usually the least efficient from the standpoint of the grower obtaining water at the time and in the quantity most desirable for his trees. It denies the grower any opportunity for decisions on time and duration of irrigation.

The demand system of water delivery is one in which the grower can obtain the amount of water he needs at the time he needs it by placing a request sufficiently in advance with his water agency. This system permits the grower to study his trees and soil-moisture condition carefully and apply irrigations with all the skill available. It results in using less water throughout a given project or district during periods of low use and more water in periods of high use according to tree need. This places a variable demand upon the capacity of the delivery system, and usually requires more capacity to serve the same acreage than is needed under the rotation system. For this reason, the demand system is not as popular with water agencies.

The continuous flow system is utilized in relatively few citrus-growing areas. It operates in much the same manner as water delivery to a home by a city water system. The water is under pressure in a pipeline and is always available to the grower whenever he wishes to turn on the valve at his takeoff point. He may use the water during either daytime or nighttime if he chooses. This system provides the maximum flexibility for the grower in irrigating under conditions most favorable to him and his trees. It also places the most severe demand upon capacity of the delivery system and is generally the most costly system. However, it may be the type of delivery system necessary for the ultimate automation of irrigation. It will be a matter of high cost equipment and high cost water replacing high cost labor and wasted water.

Units of Water Measurement

Three types of water measurement are of interest to irrigators. These are measurement of flow, volume, and depth on the land. Units of flow commonly used in irrigation practice in the English system include cubic feet per second (cfs), gallons per minute (gpm) and miner's inch. Under the metric system, units of flow include liters per second and cubic meters per second. Table 8–9 shows the relationship between the various units of flow.

The common units of volume are cubic (cu.ft.), gallon (gal.), acre-inch (ac.in.) and acre-foot (ac.ft.) under the English system and liter and cubic meter under the metric system. Units of depth used are inches and feet under the English system and millimeters under the metric system. Conversion of these units from one system to the other is shown in Table 8–10.

The miner's inch is a unit of flow having different definitions in different locales. It was

Table 8–9
CONVERSION TABLE FOR UNITS OF FLOW
(Equivalent values are given in the same horizontal line)

Cubic Feet Per Second	Gallons Per Minute	Southern California Miner's Inches	California Statute Miner's Inches	Liters Per Second	Cubic Meters Per Second
0.00223	1.0	0.1114	0.0891	0.063	0.00006
0.020	8.98	1.0	0.80	0.567	0.0006
0.025	11.22	1.25	1.0	0.709	0.0007
0.0353	15.85	1.77	1.41	1.0	0.001
1.0	448.8	50.0	40.0	28.32	0.0283
35.31	15,847.0	1,765.0	1,412.0	1,000.	1.0

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Table 8–10
CONVERSION TABLE FOR UNITS OF DEPTH, AREA, AND VOLUME

Depth			Area			Volume	
Inches	*Feet*	*Milli-meters**	*Acre*	*Dunam*	*Hectare*	*Acre-Feet*	*Cubic Meters*
1		25	1	4.05	0.4	0.81	1000
2		50	2.47	10.	1.0	1	1235
						Acre-	
3		75	5	20.2	2.0	*Inch*†	
4		100	10	40.5	4.1	1	103
						Cubic	
6		150	20	81.0	8.1	*Yard*	
8		200	24.7	100	10.0	1	0.76
10		250	40	162.0	16.2	1.31	1
						Cubic	
12	1	300	80	324	32.4	*Feet*	
15		375	100	405	40.5	35.3	1
							Gallons
18		450	120	487	48.7	1	7.48
21		525	123	500	50	0.1337	1
24	2	600	160	648	64.8	*Liters*	
30		750	247	1000	100	3.79	1
36	3	900	320	1296	129.6	1	0.264
42		1050	640	2592	259.2		
48	4	1200					

* Low by 1⅓ per cent for easy conversion.
† 1 acre-inch per acre = 25 cubic meters per dunam.

adopted from the early mining industry during its development in the western United States and was defined in laws passed by the various states. It is still used in measuring water for many of the older irrigation enterprises. In Southern California, Utah, Idaho, New Mexico, Washington, Kansas, Nebraska, North Dakota, and South Dakota, 50 miner's inches = 1 cfs. In Northern California, Arizona, Montana, Oregon and Nevada, 40 miner's inches = 1 cfs. In Colorado, 38.4 miner's inches = 1 cfs. The cubic feet per second is the more commonly used unit of flow in modern irrigation developments using surface water supplies, while gallons per minute is the unit usually employed for pump discharges.

In irrigation practice, it is frequently desirable to convert a flow rate operating over a given period of time to a depth of water applied to the land. This is done for English units by referring to table 8–9 and converting the units of flow to cubic feet per second, if they are not already known in this unit. The remaining conversion is accomplished through use of the formula:

$$\text{Approximate average depth in inches} = \frac{\text{Flow in cfs} \times \text{hours run.}}{\text{Area in acres}}$$

The formula under the metric system is as follows:

$$\text{Approximate average depth in millimeters} = \frac{\text{Flow in cmh} \times \text{hours run}}{10 \times \text{area in hectares}},$$

where cmh equals cubic meters per hour.

Theoretically, the measurement of water is a simple operation, but practically it is often complex and subject to considerable error unless the equipment for making the measurement is of high quality and conditions for its operation are satisfactory. It is partly for this reason that irrigation recommendations are phrased in terms of the length of time water is applied (see p. 252) rather than the *amount* of water applied. The grower is justifiably less concerned with how much water he puts on (until he receives the water bill) than he is with how deeply and how well he wets his soil.

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METHODS OF IRRIGATION

Efficient irrigation consists in wetting the soil mass occupied by the root system of the irrigated crop without excessive penetration below the root zone, without excessive waste by surface runoff, and with reasonably uniform application to the area intended for irrigation. Because citrus is commonly grown in areas of relatively high land values with limited and expensive water supplies, a higher degree of efficiency in the use of irrigation water is required than is usually necessary for other irrigated crops. Efficient irrigation is only possible through the use of proper methods of application.

The main factors governing the choice of methods are: (1) method of delivery of the water (open ditch or underground pipe, high or low pressure); (2) size of stream and duration of flow; (3) topography and slope of the land; (4) soil characteristics (particularly infiltration rate and water storage capacity); (5) the quality of the irrigation water; and (6) the cost of the irrigation water. Methods of irrigation are sometimes chosen to conform to what happens to be common or popular in the area without sufficient concern for the factors which should govern choice.

In general, the methods used for most citrus are surface irrigation and sprinkler irrigation. A new method called drip or subsurface irrigation has aroused great interest among growers and scientists and is being tested in experiments and on farms. At this writing insufficient facts are known about it and experience is too limited to permit making definitive statements. Because of this, the following sections are devoted mainly to surface and sprinkler irrigation but contain a few comments about drip and subsurface irrigation.

Surface Irrigation

Surface irrigation is the application of water by gravity flow directly to the surface of the soil. Distribution on the ground depends on the flow of water across the surface of the land in response to slope and the direction or confinement of this flow by soil ridges, dikes, or furrows. Surface irrigation is generally used where water is received in open ditches or in pipes under low pressure. In surface irrigation, a wide range of flow rates can be handled, but a high flow rate is often most efficient and economical except where infiltration rates are very low. A high flow rate permits covering the ground uniformly and in a short period of time so that the job is completed and labor freed for use elsewhere.

Border Method.—The border method employs a series of parallel levees extending downslope through the orchard, the areas between levees being flooded in the process of irrigation. The levees may be left throughout the season or constructed before and torn down after each irrigation. In general, the method is adapted to coarse-textured soil on relatively flat slopes. The slopes must be uniform with very little cross slope and some land grading is generally necessary before planting the orchard. The border method is not suited to the use of small flows of water. A border is usually one tree row wide and will include 8 to 16 trees.

Border irrigation is useful where the soil or the water tends to be salty. There is just the one ridge left above water during irrigation on which salt can accumulate by capillary rise of water, and this ridge is midway between trees (fig. 8–13). By proper irrigation, the rest of the soil can be washed free of excess salts.

To obtain uniform distribution of water from the top to the bottom of the run, the length of run and flow rate of water must be selected to match the slope and infiltration capacity of the soil. Marr (1954) and Core (1951) provide tables from which the proper length and water flow rate may be selected.

Basin Method.—For basin irrigation, the orchard is divided into a series of squares or rectangles by means of levees and cross levees (figs. 8–14 and 8–15). Conditions of soil type, age of

Fig. 8–13. Border irrigation. Note border ridge midway between tree rows, an advantage for saline conditions.

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trees, slope of land, and size of irrigation stream determine the size of basin to be used. Usually there is one tree to a basin, but sometimes a basin may serve several trees. Success depends on the selection of a basin of proper size and the construction of a substantial levee system which will hold the desired depth of water.

In applying the water, the basin nearest to or farthest from the source of supply may be filled first. If the basin nearest the source of supply is filled first, the levees are built without breaks between the basins. When the first basin has filled, the levee separating it from the one below is cut, and the water is drained from the upper basin into the one below. When the irrigation of the row has been completed, the lower basins are left filled or partly filled with water, and little standing water remains in the upper ones. This method of cutting from one basin to another is used only on coarse-textured soils with flat grades. When the lower basin is irrigated first, an opening is left in the levees separating the basins so that the water can run through to the lower basin first. When this basin has been filled to the desired depth, the opening is closed and the one above is filled (fig. 8–14).

A more desirable method, especially useful as a means of applying uniformly shallow depths of water to coarse-textured soils, is to construct a temporary ditch between alternate tiers and deliver water directly to each basin. Occasionally, portable pipe or canvas hose is used for direct delivery of water from the pipeline to each tree basin.

Fig. 8–14. Basin irrigation with levees around each tree.

Fig. 8–15. Basin irrigation on Zebediela Estates, Republic of South Africa.

The principal advantage of the basin system of irrigation is that a uniform depth of water may be applied to each tree if single-tree basins are used. Field observations have shown, however, that there is a hazard of gummosis (*Phytophthora* infection), especially on fine-textured soils, where the soil in contact with the tree trunk has been irrigated. The basin method should be avoided for fine-textured soils. The continuous attention which the method requires makes it generally impracticable for night irrigation.

Furrow Method.—The furrow method of irrigating citrus orchards has been used extensively over a wide range of soil type and topography. It permits the use of small flows of water, and the direction of the furrows can be tailored to the slope and topography of the land to provide a suitable gradient in the furrow. On soils of low permeability, the application of water may be continued with a minimum of attention until a desired degree of penetration has been obtained. Conditions unfavorable to use of furrows are erodible soils on slopes exceeding 3 to 5 per cent (the limiting slope depends on the soil erodibility), flat grades with very porous soils, or undulating land with frequently changing slope direction.

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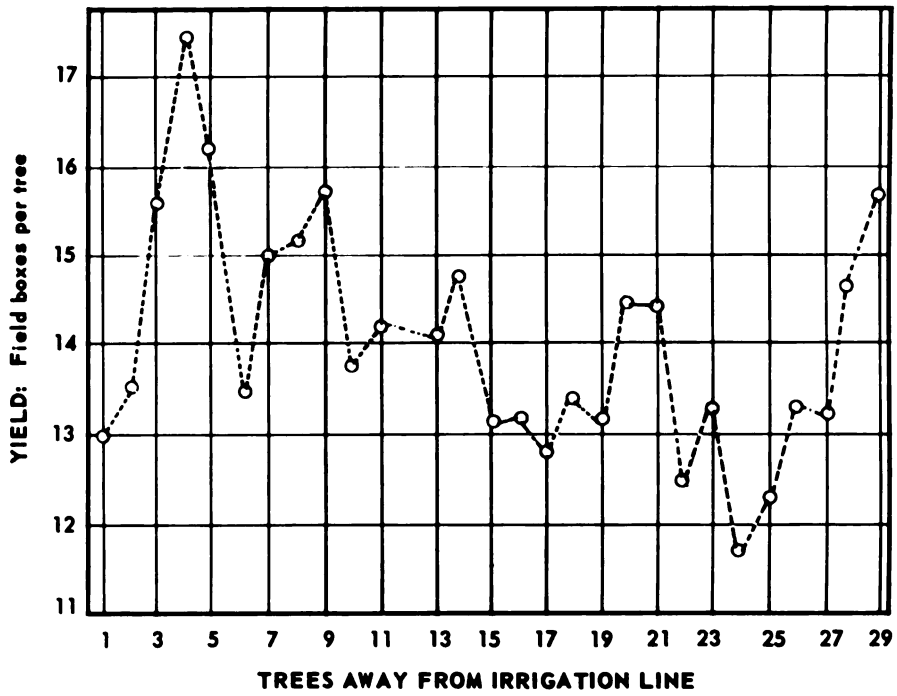

Fig. 8–16. Effect of distance from irrigation line on production of Valencia oranges in Salt River Valley (From Hilgeman and Rodney, 1961. Courtesy of Arizona Agricultural Experiment Station.)

Even with a uniform grade and care in regulating the flow, it sometimes is not possible to obtain uniform penetration throughout the length of the run. Good penetration may be obtained in the upper quarter of the run with gradually diminishing penetration to a point about three-quarters down the run. Frequently water penetration improves in the lower quarter because of ponding at the end of the run or because of slope decrease and deposition of soil eroded from the upper portions of the run. Observations made the day after irrigation, using a soil auger at various distances down the run or with tensiometers previously placed in the upper and lower halves of the run, reveal the differences in water penetration obtained. The effect of these differences in water penetration on orange production in the Salt River Valley of Arizona is shown in figure 8–16.

Adverse distribution down the run usually implies that the run is too long in relation to soil, slope, and water flow. The first step in attempting to correct such a situation is careful attention to irrigation flows in each furrow so water will reach the end of the furrow in 25 per cent of the total duration of application as described on page 275. This will improve the distribution if furrows are not too long. If furrows are too long, the best solution is to shorten the run by installing additional pipelines. This may require more labor for irrigation as well as an expenditure for more pipelines, but the improved fruit production may bring good returns on the additional investment. Hilgeman and Rodney (1961), from whom the data in figure 8–16 were obtained, estimated that the drop in yield in the lower half of the run resulted in the loss of at least 110 field boxes of fruit per acre.

The lateral movement of water from an irrigation furrow varies with the type of furrow and the nature of the soil. Furrow irrigation seldom achieves 100 per cent wetting of all the soil from tree to tree, nor is this necessary. Experiments reported by Huberty and Richards (1955) showed that wetting only 40 per cent of the root zone at each irrigation gave essentially the same yield as wetting 80 per cent of the root zone, provided irrigation was on a frequent schedule. Kuraoka *et al.* (1957) concluded from experiments in which only a portion of the roots obtained water that one half of the root zone should have adequate water at all times. In certain soils, wetting even half of the soil in the root zone may be difficult under some systems of furrow irrigation. For this reason, various types of furrows are used.

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Fig. 8–17. Six narrow V-shaped furrows in a tilled orchard.

In tilled orchards, where the furrows are remade for each irrigation, from four to eight narrow V-shaped furrows are used between each row of trees (fig. 8–17). These furrows will handle relatively small flows of water, but since several are used and the flow has to continue for an extended period of time because of its slow rate of advance down the run, a substantial percentage of the entire soil is usually wetted. This system is most useful in medium- to fine-textured soils.

Fig. 8–18. Broad-based furrows.

The broad-based furrow has met with increasing favor among citrus growers (fig. 8–18). A broad, flat furrow permits the wetting of a larger soil surface area than is accomplished with V-shaped furrows. This permits a more rapid intake of water for soils which might have infiltration rate limitations. It also permits the use of a larger stream of water in each furrow, so that the water can be hurried to the lower end of the run in shorter time and a more uniform irrigation can be achieved, an advantage for soils which range from medium-textured to moderately coarse-textured. Thus, the broad-based furrow provides some assistance in the irrigation of soils where the infiltration rate tends to be rapid, and it also provides some advantage in the irrigation of soils where the infiltration rate tends to be slow, providing the slope is not too great.

Various numbers of furrows between tree rows are employed, depending upon the circumstances and need. With young trees, there may be only one furrow on each side of the tree row within a foot or two of the row. In some cases, a single furrow is run right down the tree row, and this may have some real advantages when the newly planted trees are balled-root and the soil in the ball differs in texture from that of the field in which they are set. As soon as the roots are well out of the ball, the two furrows can be used and gradually pulled away from the tree (fig. 8–19). As the tree grows and its root system spreads, the furrows can be pulled further away and additional furrows added as needed. The critical point with young balled-root trees is to make sure that one does not have a dry ball. If the tree ball remains dry, the tree will suffer or perish before the roots can extend into the wetter soil beyond. As soon as the tree roots have moved out into the adjoining soil, care should be taken not to irrigate too often. Over-irrigation at this time can be damaging, particularly from the standpoint of gummosis. The use of tensiometers is strongly recommended for regulating the irrigation of young citrus trees because their needs differ from larger trees, and the schedules for mature trees are likely to be incorrect.

As trees grow larger, from three to eight furrows are used, fewer being needed with broad-based furrows than with the narrow, V-shaped furrows. When four or five furrows are used, it is very likely that any vehicular traffic will have its wheels running in one or possibly two furrows. This will cause soil compaction, which in turn

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Fig. 8–19. Two furrows in a young orchard. Later one or more additional furrows will be added. Fig. 8–20. Furrows in a near-contour-terraced orchard.

will influence the infiltration of water and the adequacy of distribution. Cultivating the bottoms of furrows might increase the rate of water infiltration under some conditions. However, the benefits of such cultivation seldom extend beyond the first irrigation, especially if the soils have a tendency to run together when the water is applied.

Since nontillage (made possible by chemical methods of weed control) has come into use, it has been fairly common to use three broad-based furrows between tree rows. They are spaced in such a way that vehicular traffic travels on the ridges adjacent to both sides of the middle furrow. Improvement of water-intake rate in orchards which have shifted to nontillage has been attributed to keeping vehicular traffic out of the furrows, to reduced compaction from elimination of tillage, and to gradual deposition of trash in the furrows, which holds back the streams of water and increases the area of soil wetted by each furrow. In some instances, nontillage has so increased the water-intake rate that growers have found their irrigations runs too long to do a satisfactory job of irrigating the lower half of the run. Rather than install additional pipelines to shorten the run, some growers have returned to the practice of tillage to reduce their water-intake rate.

In coarse soils on flat grades, it is advisable that the furrows do not exceed 160 feet in length. As the grade increases or the soil becomes finer textured, the length may be increased. In fine soils which infiltrate water slowly, a length of 660 feet is occasionally used. Uniformity in moisture penetration usually decreases with increase in the length of run, and runs in excess of 330 feet should normally be avoided.

Orchards on steeply sloping land are sometimes planted on the near contour and irrigated by furrows which have a modest slope in the direction of water flow (fig. 8–20). The necessary slope can usually be designed into the system. With proper orchard layout, the degree and uniformity of the slope can be made to match the existing soil stability and infiltration capacity. It should therefore be possible to accomplish a good job of irrigation with near-contour furrows. The main problem is that the length of the runs are variable, so that different sizes of stream are needed to insure that each row receives a uniform distribution of irrigation water.

There are various devices and techniques for admitting water to the upper end of furrows and controlling its rate (figs. 8–19 and 8–21). With furrow irrigation, a drain system is usually provided at the bottom ends of the runs so that the waste water can be carried off without causing erosion (fig. 8–22). It may either be wasted into a convenient drainway, applied to another lower-lying section of the orchard, or led into a sump from which it is recirculated by means of a pump and a pipeline back to the inflow end of the same section of the orchard from which the run-off originated. If water is expensive, the run-off should be recaptured. Even when water must be pumped back to the upper end of the field from which it started, it is generally cheaper per acre foot than the water initially used. Recirculating systems have become numerous in some areas, particularly in the San Joaquin Valley of California.

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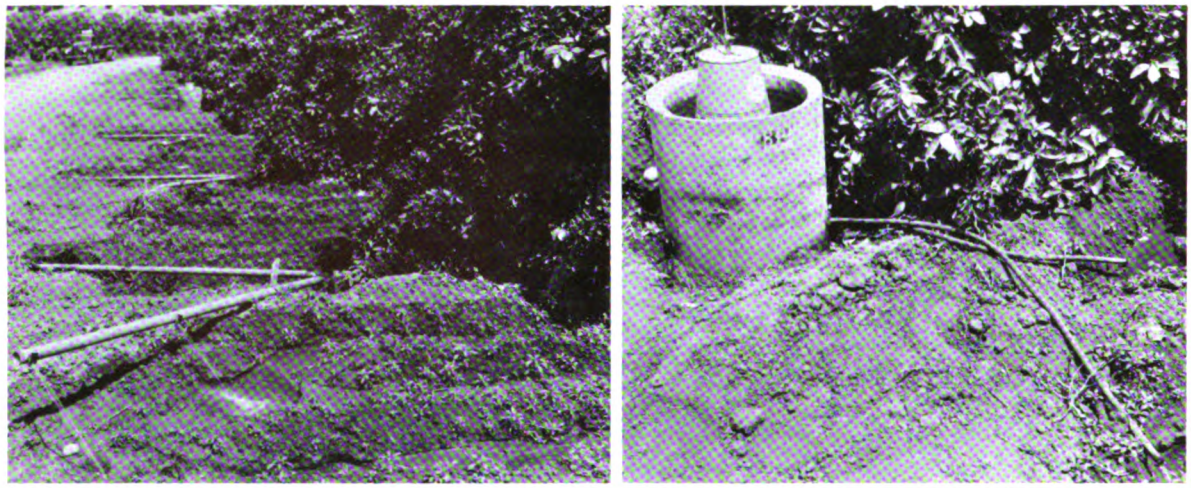

Fig. 8–21. Methods for distributing water in furrows. Left, gated pipe which can be pivoted out of the way for orchard operations. Right, plastic hose connected to a riser is easily managed and discharges a less erosive stream.

Sprinkler Irrigation

Sprinkler irrigation has become increasingly popular with citrus growers. In many places, a rather high percentage of new citrus planting has started out with sprinkler irrigation and in some places growers have converted from surface irrigation methods to sprinkler irrigation in mature orchards. In some situations, sprinkler irrigation is more satisfactory than surface methods, but this is not always the case and a decision to use sprinkler irrigation should be based on a sound evaluation of the factors involved.

Usefulness of Sprinklers.—Sprinklers have a decided advantage on steep land of nonuniform topography. Such land requires considerable grading for surface irrigation, and runs would be of various lengths in different directions, causing problems both in system design and operation. Part of the extra cost of sprinkler-irrigation systems over surface systems is recovered by the lack of any need for grading the land. In areas of steep slopes and nonuniform topography, soils are often of variable depths. Land grading necessary to prepare soils for surface irrigation may remove the much needed top soil from some areas, leaving infertile and hard-to-manage subsoil exposed.

Fig. 8–22. Waste water collection system.

Good labor, willing and able to handle surface water, is increasingly difficult and expensive to obtain. However, less skilled labor can conduct the necessary chores on sprinkler systems, which are often designed so that they may be operated by the turn of a few valves with little labor required. Other than an occasional check to insure that sprinklers do not become plugged or otherwise inoperative, there is little need to "stay with the water" during the course of an irrigation. The reduction in labor cost can be considerable, and some growers calculate that even expensive complete installations are cheaper in the long run because of reduced labor cost.

Other factors related to the soil sometimes favor sprinkler irrigation. The difficulty of obtaining uniform irrigation from the top to the bottom end of a run with surface irrigation has been mentioned. Sandy soils of high permeability are

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extremely difficult to irrigate uniformly with surface methods and then only if large water flows are available. With a properly designed sprinkler-irrigation system, a reasonable degree of uniformity is insured from one end of the orchard to the other. Within the range of coverage of a single sprinkler, there is often a lack of uniformity which reaches proportions of two to one or greater, but this localized lack of uniformity is not critical except with widely spaced, over-tree sprinklers. It has been pointed out previously that citrus does very well with only 40 to 50 per cent of its root zone wetted if the wetting occurs frequently enough.

In some fields, soils vary considerably, and the amount of water absorbed from surface irrigation would vary correspondingly. Such soil variations have no effect upon the amount of water received from a sprinkler irrigation, unless the application rate from the sprinklers exceeds the minimum infiltration capacity of the soil. Some soils have a limited depth overlying coarse sand, gravel, or other material. Distributing the correct amount of water to refill this shallow root zone without losing considerable quantities by deep percolation can be difficult with surface-irrigation systems, but is easily accomplished with a sprinkler system. At times in the spring, the upper foot of soil drys slowly as the growing season commences, but the soil below is still cold and very wet. A light irrigation might be helpful at such times in preventing trees from suffering stress during a sudden, short period of hot weather. Such an irrigation would be difficult to accomplish with most surface-irrigation systems without adding excessive amounts of water in the cold, already-wet lower half of the root zone, but it would be relatively simple with a sprinkler-irrigation system.

In some areas, the water supply is provided on a more or less continuous basis, sometimes under pressure, so that the grower can merely turn on a valve and have water when he needs it. With such a system of supply, it is convenient to design sprinkler irrigation which can efficiently utilize small flows. Surface irrigations often cannot operate efficiently with small flows.

When a grower is faced with some or all of the conditions described which favor sprinkler irrigation, it is logical for him to choose the sprinkler-irrigation method for his orchard. Where a grower faces conditions which favor irrigation by surface methods, it seems unwise for him to attempt to switch from an already-installed surface system to the sprinkler method. A grower with uniform soil of moderate permeability, smooth topography, and even slope, having a water supply delivered in a fairly large-sized stream in rotation, can do as good a job of irrigation and probably do it more cheaply with surface methods than by installing a sprinkler system. Using surface methods, an irrigation can be accomplished in a few days, with the remaining interval between irrigations left free for other purposes. With sprinkler irrigation, the water usually is running in some part of the orchard almost all the time. If a grower is not obtaining a sufficiently uniform distribution of water because his runs are too long, he should carefully calculate the relative costs of putting in additional pipelines versus those for installing a sprinkler-irrigation system. This cost analysis should include an estimate of the labor required to accomplish the irrigation as well as the capital costs involved. The grower should then use whichever method the cost analysis favors, and if there is very little difference between the two, he would probably be wise to stay with his present method.

There are some orchards which have shown signs of deterioration and reduced yields as compared to former years. Frequently, an examination of the root system shows that the roots are not healthy and have disappeared from beneath the furrows. Irrigation is often suspected to be the cause. When such a situation exists and the grower believes that irrigation is responsible, he is inclined to switch to sprinkler irrigation as a means of restoring orchard productivity. If the problem is caused by poor distribution of water because runs are too long or a difficulty in avoiding excess irrigation with the present method of handling water, a change to a sprinkler system may provide better conditions. As mentioned above, an analysis should be made to determine whether or not an improvement of the present surface-irrigation system might not accomplish the same objective.

The problem, however, may be caused by nematodes or other trouble in the root zone not related to irrigation at all. It may also be caused by improper frequency and amount of irrigation, particularly in the spring of the year. These problems will not necessarily be improved by switching to sprinkler irrigation, and the grower may experience considerable disappointment within a year or two after making such a change.

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There are some dangers in the use of sprinklers which the grower should recognize. One of these is the absorption of salts from irrigation water by the citrus leaves. Harding *et al.* (1958) reported a study of damage to citrus trees irrigated by sprinklers with water containing from 500 to 900 ppm of soluble salt. The injury occurred only on those leaves hit by spray from the sprinklers. It did not occur on those leaves not reached by the sprinkler water nor on those trees irrigated by surface methods using the same water. The injury was more prominent on the windy side of the tree, and was more likely to occur when the irrigation was performed in hot, dry, windy periods. Analysis of the leaves showed that they had absorbed considerable amounts of both sodium and chloride. Sodium in the leaves ranged from 0.41 to 1.30 per cent, while the chloride ranged from 0.16 to 1.31 per cent. Chapman (1950) has stated that leaf content greater than 0.25 per cent of either sodium or chloride is excessive. (See also chap. 6.)

Fig. 8–23. Over-tree sprinklers stand high above young orchard, but trees grow up around risers which are 20 feet tall and placed close to a tree to be away from orchard operations.

Eaton and Harding (1959) found that higher concentrations of soluble salt in irrigation water were required to produce leaf damage when evaporation was low than under dry, windy field conditions producing high evaporation. Further observations and field experience have shown that it is the high evaporation of water from the leaves, causing concentration of the solution on the leaves, which leads to absorption and damage. This high evaporation occurs under high temperatures, low humidity, and possibly windy conditions when irrigating with rotating sprinklers which wet the leaves and then permit a period of time for evaporation before they are wet again. A continuous wetting without the intermittent evaporation periods is not as damaging (Ehlig and Bernstein, 1959). It is now believed that sprinkler irrigation in dry, low humidity climates should not be performed with water containing more than three meq/l of sodium or chloride if the sprinkler water hits a significant proportion of the citrus leaves. Somewhat greater concentrations of salt in the sprinkler water can be used if the sprinkling is done under nonevaporative conditions such as are found in cool, coastal climates or at night, or if the sprinkler throws a spray which hits very few of the leaves on a tree. Some sprinklers do not throw water higher than about 2 feet above the ground surface, and the loss of some leaves at this level would presumably not be too damaging.

Another hazard from sprinkler irrigation of citrus that has caused some concern is the incidence of brown-rot gummosis. This seems to occur when the sprinkler water hits the trunk of the tree, and the soil immediately around the base of the trunk remains wet for some time after irrigation. Field evidence has been somewhat conflicting on this point. Brown-rot gummosis has been serious in some young citrus orchards irrigated with fixed-jet sprinklers directed against the trunk of the tree, while in others there has been little or no damage. As trees get older, and the foliage creates a protective skirt, tending to maintain a higher humidity around the trunk, it seems prudent to move the sprinklers away from the trunk of the tree out to the middle between tree rows so that a minimum of water will actually reach the trunk.

Types of Sprinklers.—Different types of sprinklers are available. The choice of type should be based upon soil and wind conditions, and also

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on quality of the water. The preference of the grower, who has seen systems in operation which appeal to him, and persuasiveness of the sprinkler salesman are more often the basis of choice. Some of the types of sprinklers will be briefly described.

Overhead irrigation systems have a medium to large, rotating sprinkler head mounted on a tall riser extending above the tree tops (fig. 8–23). The riser is usually a metal pipe attached to a lateral system which may be laid on the surface of the ground or buried beneath it. The spacing between sprinklers on the lateral is usually about 60 feet and the distance between laterals, 50 to 80 feet. With large sprinklers, spacings may be greater. The height of the risers plus the pressure at the head necessary to obtain good distribution with the large heads and wide spacings requires a pump pressure of 75 to 125 pounds per square inch. In areas with porous soils that absorb water as rapidly as it falls, and with no serious wind conditions, overhead irrigation works quite well and requires relatively little labor. If strong wind is a problem for more than a few hours a day, the uniformity of distribution will likely be poor and this method of irrigation not too satisfactory. The system has one potential advantage which has been very little exploited to date: that is its ability to increase the humidity and modify the climate within an orchard on very hot days. There is also the possibility that it could be used for frost protection on cold nights during the winter, a use described more fully in the following section. Over-tree irrigation can not be used with water quality and climatic conditions which would produce leaf burn as described in the previous section.

There are several types of under-tree sprinkler irrigation systems in use. One type has portable aluminum lateral pipe to which low-angle, rotating sprinkler heads are attached by means of a short, 6-inch riser. Spacing of sprinklers on the line may be at distances of 20, 30, or 40 feet. The distance between lines is usually the width of two tree rows. Because distance and the interference of the trees limit the amount of water reaching through the tree row from the irrigated middle to the adjacent middle in which a line is not placed, the middle in which the lines are placed is alternated with each irrigation. While the trees interfere somewhat with the uniformity of distribution of the water, this is of no great concern for reasons previously mentioned.

In Florida, perforated, portable aluminum lateral pipe is used (fig. 8–24). The lines are towed by tractor for moves down a line of trees, but must be carried in sections when moved across tree rows. The application rate tends to be higher than that of rotating sprinkler heads but the sandy soils are capable of absorbing high application rates.

A modification of the under-tree system has become popular. Sprinklers having a very low rate of output are used, one to each tree. The orchard may be equipped with plastic distribution lines of 2- to 4-inch diameter, which are usually buried with risers and valves at every other tree row. To the valve is connected a ½-inch-diameter plastic flexible hose resembling a garden hose. On the end of this hose separated by sections of hose equal in length to the distance between trees are three sprinklers (fig. 8–25). Sometimes only two will be used and sometimes as many as five, de-

Fig. 8–24. Perforated pipe sprinklers. Left: applying the water. Right: moving a line by tractor.

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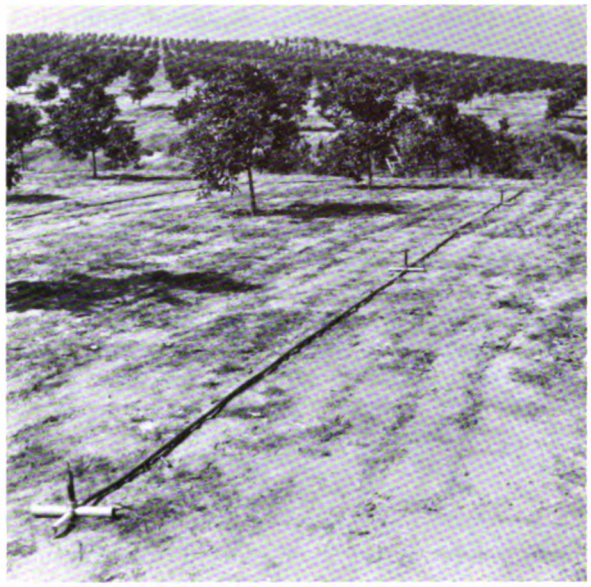

pending upon sprinkler discharge and water flow capacity of the hose.

To start an irrigation, the hose is stretched out to its full length along a tree row and run for a period of time sufficient to give the desired application. Application times are usually 12 or 24 hours, though 18 hours may be used. The application rates are usually from 0.1 to 0.15 of an inch per hour so that in 24 hours from 2.4 to 3.6 inches of water will have been applied. When the irrigation is completed for a particular setting, the hose is pulled towards the valve by an operator standing on dry ground or riding in a small motorized cart on dry ground, (Wolfe, 1962). After each set, sprinklers are pulled a distance of three trees until eventually they reach the valve and riser. They may then be dragged in the opposite direction from the valve to the full extent of the hose and gradually pulled back three trees at a time towards the valve. When that is completed, the hose and sprinklers can be pulled over to the opposite side of the tree row and the operation repeated in the next middle. In this manner, a single hose with three sprinklers can irrigate 48 trees over a period of 16 days if 24-hour settings are used.

Moving the drag lines requires some labor, so growers who want to minimize all labor in conducting their irrigations install permanent underground plastic pipe instead of using the drag line. A riser to which a sprinkler head is permanently attached occurs opposite each tree or each tree space. For a producing orchard, this will be a rotating head located in the middle of the square between four trees. These rotating sprinklers will have a diameter of coverage ranging from 20 to 30 feet, so that they do not project water into the adjacent tree row and therefore need to be placed between every row of trees.

There are several variations of this type of installation. Sometimes the line is buried about 5 feet from the tree row and a riser occurs directly opposite the tree. When the trees are very young, a fixed-jet sprinkler is used on each riser which covers a part circle or pie-shaped pattern sufficient to wet all the root zone for trees up to three or four years old. In a few cases, the fixed-jet sprinkler will be left until the trees are much

Fig. 8–25. Hose-pull system. Top: three-tandem sprinklers on a hose opposite each tree. Center: three-tandem sprinklers opposite alternate trees. Bottom: changing sprinklers by pulling hoses while standing on dry ground.

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larger, but this tends to restrict the eventual root development of the tree. Usually after the trees are three or four years old, the fixed-jet spray nozzle is replaced with a rotating head which will cover a circular pattern more nearly equal to the expected root distribution of the tree.

Another variation is to place a lateral distribution line above ground when the trees are young. The line is equipped with fixed-jet sprinklers opposite each tree (fig. 8–26). As the trees grow, the line is gradually moved away from the tree row. When it gets too far away for the fixed jet to perform adequately, the jet is replaced by rotating sprinklers. Eventually the line is in the middle between two rows of trees. When this position is reached, the line may be permanently buried.

Another modification is to bury the line initially in the middle between the tree rows and equip the riser with a special sprinkler head. The sprinkler head is adjusted to provide a fixed spray with a long, narrow oval pattern reaching to the tree (fig. 8–27). When the trees attain greater size, an adjustment converts this same sprinkler to a rotating type, which is then capable of wetting the entire area between trees.

Because risers in the middles often interfere with other orchard operations or are subject to damage, some systems consist of buried laterals with risers close to the trees. Each sprinkler is attached to one end of a plastic hose of 6- to 10-foot length, the other end of which is connected to a riser. The sprinkler can be placed where needed for irrigation and pulled beneath the tree during picking or other orchard operations. No moves are needed during an irrigation.

Fig. 8–26. Sprinkler and tensiometer close to young tree. Fixed-jet sprinkler and tensiometer (covered by cap) are positioned at about the drip-line and moved as the tree grows.

Fig. 8–27. Long oval spray pattern from fixed-jet sprinkler, which later becomes a rotating sprinkler.

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Drip Irrigation

Drip irrigation is the frequent slow application of water at particular points from mechanical devices called emitters. When correctly designed, the rate of application is so slow that little or no flow of water occurs on the soil surface. Emission rates generally used range from 0.5 to 2.0 gallons per hour. After emission, all water movement is by capillary flow within the soil. To achieve adequate wetting of the root zone soil, one or more emitters per tree are used, depending on the size of the tree and the ability of the soil to permit lateral movement of water away from the emitter.

Emitters are usually connected to a small diameter plastic lateral line that extends parallel to the tree row. It may either be buried slightly between trees or lie on the surface. Laterals range from ¾-inch to ⅞-inch diameter in lengths of 300 to 600 feet, and there usually are one or two laterals per tree row. In orchards equipped with buried pipe lines for permanent solid set sprinkler systems, a short lateral may be attached to the riser at each tree and laid in a circle around the tree. This permits great flexibility in placement and number of emitters per tree.

Economic considerations will probably limit the number of emitters per tree or per acre that can be used, and the inability to wet as large a root volume as with standard methods is generally conceded. This creates the need for frequent irrigations, each of limited volume to avoid overwetting the soil. Irrigations are generally applied daily or on alternate days, running enough hours to apply the presumed needs of the tree. At present the peak consumptive use needs of trees irrigated by this method are not precisely known. New plantings seem to do well with about 2 to 3 gallons per day per tree, middle-sized trees with 10 to 15 gallons per day per tree, and mature trees with 25 to 50 gallons per day per tree. Additional research and experience may change these figures.

If a mature tree needs 35 gallons per day per tree and is equipped with 3 emitters rated at 1 gallon per hour, irrigations would be applied 12 hours daily or 24 hours on alternate days. Various other combinations of emitter numbers, output rates, and hours of operation can be used. Output rates must be kept low enough to avoid surface runoff.

At this time many questions remain unanswered. These include: will emitters continue to flow reliably over extended periods of time?; will harmful salt accumulations develop in the root zone?; will mature trees have sufficient anchorage, and will they yield satisfactorily with a small root volume?

Emitter performance will be improved as manufacturers gain experience. More experience and research are needed to answer many other questions. Proper cleaning of the water used for drip irrigation is important, even with waters thought to be clean. Various types of filters and screens are used depending on local availability. Screening may be in multiple stages with the final stage being about 200-mesh size.

Some emitters are intended to be used only on the soil surface while other types are designed to operate either on or beneath the soil surface. Still others are intended to operate only beneath the soil surface. Subsurface irrigation is the term used when emitters are placed beneath the soil surface, but water movement in the soil is mostly by unsaturated flow as with drip irrigation. This should be distinguished from an earlier practice called "subirrigation." Subirrigation is the intentional raising of the water table to saturate the root zone followed by rapid drainage. There are few soil conditions with which it can conveniently and safely be conducted and very little citrus acreage is irrigated this way.

Alternate Middle Irrigation

Alternate middle irrigation is a technique which can be practiced with either sprinklers or furrows if water quality is good. It consists of applying water only to every other middle between tree rows, leaving half the middles unwatered. At the next irrigation the previously unwatered middles are irrigated, and the previously irrigated middles are left unirrigated. In the practice of alternate middle irrigation one side of every tree in the orchard receives water at each irrigation.

There are several reasons why alternate middle irrigation is employed, though it is often practiced without any particular reason. If the grower is faced with a water shortage, so that it would be impossible for him to apply as much water during some period of the year as the trees need, he can cushion the effect of this water shortage by using alternate middle irrigation. The method stretches a short water supply so that the trees will be partly thirsty all the time, but not run completely out of water at any time.

Alternate middle irrigation is sometimes used in fine-textured soils as a means of avoiding excessive wetness. The nature of fine-textured

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soil is to lose water rapidly from the upper quarter of the root zone and very slowly from the lower three-quarters. When the easily conducted water has been removed from the upper quarter of the root zone, there may be plenty of water left in the lower three-quarters, but it may be available too slowly to supply tree needs during peak demands. If the entire soil is irrigated when the upper quarter has dried partially, there is a danger of having the soil too wet much of the time. With alternate middle irrigation, one side of the tree has a good supply of water in the upper quarter of the root zone, while the opposite side of the tree continues to extract the more slowly available water remaining in the lower three-quarters of the root zone. A more thorough drying of the soil mass is possible between irrigations, which is sometimes beneficial to the root system and may be an aid in overcoming chlorosis tendencies in calcareous soils.

Where portable sprinkler irrigation systems are used, there usually is insufficient equipment to cover the entire orchard within a reasonable length of time if both sides of every tree are irrigated. Alternate middle irrigation provides a means for getting over the orchard in a shorter time, so that there is less likelihood that the interval between irrigations will be long enough that trees become stressed.

Alternate middle irrigation is based on the theory that water absorbed by any portion of the root system is freely translocated to any part or all of the branches and leaves of the tree. On the other hand, it has been generally accepted that nutrient minerals absorbed by the roots on one side of a tree are translocated upwards largely to the aerial portion of the tree above the roots where the absorption occurred, and that they will not be translocated appreciably across the tree. Furr and Taylor (1934) conducted experiments to determine whether true cross-transfer of water actually did occur. They excavated around lemon trees in the field at a time when the soil was fairly dry and cut off roots from various-sized sectors of the root system. Fruit measurements were made for several days after cutting the roots. Because the soil was fairly dry, the fruit shrank on all trees though fruit on the uncut trees shrank only slightly during the day and recovered at night. Fruit on the cut trees shrank as much as 20 per cent. The severity of shrinkage depended upon the amount of roots cut. Fruit measured directly above the portion from which the roots had been cut shrank slightly more than over the uncut roots, but the difference was not great. When irrigated, fruit on the uncut trees spurted to new growth, while the cut trees merely erased their losses, except for the two most severely cut trees which recovered only part of their loss. From these data, Furr and Taylor concluded that cross-transfer of moisture from roots to tops of the citrus tree seems assured, though in the experiment it was retarded in reaching the leaves until the tree had an opportunity to make adjustments. They noted that a tree will stress more easily with only part of its root system in wet soil.

Kuraoka *et al.* (1957) also conducted a root pruning study in an effort to determine the validity of the cross-transfer of water. Roots were radially pruned to represent one-fourth, one-half, and three-fourths of the total root system. Water was immediately applied to the soil. After about 20 minutes, wilting appeared on the tree from which three-fourths of the roots had been pruned, and a slight wilting appeared on the tree from which one-half of the roots had been pruned. There were no symptoms on the tree with only one-fourth of its root system removed. On the tree which lost three-fourths of its roots, the wilting symptoms appeared only on the root cut side. Wilting disappeared in the evening, but occurred again the following morning. Wilting symptoms gradually disappeared on the trees more severely cut until about a week later no symptoms could be observed. Apparently an internal adjustment took place. From the experiments, the researchers concluded that one-half of the root zone should have adequate water at all times.

These studies support the theory that cross-transfer of water in citrus trees can take place, particularly after a period of adjustment, but the water does not move quite as rapidly or freely as in upward translocation from roots to the branches directly above the roots. Therefore, alternate middle irrigation is a practice which can be useful under certain conditions as long as the grower is aware that a tree which has become quite dry on one side and is becoming partially dry on the other side will be in a precarious position if a high transpiration period should occur.

Taylor (1939) believed that alternate middle irrigation could be useful, but suggested that its best use would be during the low transpiration seasons of the year. It is during these seasons that growers who have to go on the usual irrigation schedule are faced with the problem of adding water when they know their soils do not need it, merely because their turn has arrived, or of passing up their turn and running the hazard of en-

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countering severe stress before their next turn arrives. Alternate middle irrigation at such seasons would be useful to avoid applying too much water and still provide some insurance against the onset of sudden hot weather.

Johnston (1953) mentioned conditions for which alternate middle irrigation might be beneficial. In addition to those noted above, he stated that growers on a fixed irrigation schedule when the interval between irrigations is too long may possibly obtain a split schedule. The intervals between irrigations would then be half as long with half as much water per irrigation. This half of the water would irrigate only one side of the trees, but the shorter intervals would prevent the trees from becoming stressed as they might under the extended intervals. Johnston also mentioned that alternate middle irrigations are useful where there are numerous replants. Water can be cut into the replants from both sides. In this way the replants can be irrigated twice as often as the older trees. This may prove all right for the first few irrigations, but subsequently care must be exercised, for replants do not need water twice as often as full grown trees after the roots have grown well out of the root ball.

Another method related to alternate middle irrigation where tree rows run east and west has been very little explored. This is alternate irrigation of the slow-drying furrows in an orchard which are usually the north tree furrow and the next one or two adjacent furrows. The fast-drying south tree furrows would be irrigated every time. This method appears promising, but its merits are yet to be demonstrated.

IRRIGATION FOR CONTROL OF SALINITY AND MICROCLIMATE

Irrigation sometimes serves purposes other than the maintenance of a satisfactory soil-water condition. The two most common purposes are control of salinity and adjustment of the microclimate.

Salinity Control

All irrigation water contains some salt, and when the water has been used by the plant, the salt remains behind and concentrates in the soil. Citrus has a relatively low tolerance for soluble salts in the soil solution and has been reported to show salinity effects at concentrations measured by the electrical conductivity of the saturation extract as low as 3 millimhos per centimeter (EC_e = 3) (Harding, Pratt, and Jones, 1958). Citrus is also sensitive to moderate concentrations of sodium, chloride, and boron.

If rainfall is not sufficient to wash the salt out of the soil and remove any damaging concentrations, the salts will have to be removed by irrigation procedures. This involves applying more water than is needed by the citrus so that the excess water percolates downward below the root zone carrying the soluble salts with it. For a leaching procedure to be effective, the soil must be well drained, for it is difficult to keep the root zone leached of excess soluble salts if drainage is not adequate to keep the water table deeper than 5 or 6 feet from the soil surface. If the water table tends to rise higher than this, artificial drainage must be installed (see p. 276).

A practical program can be used by citrus growers to maintain the salt concentration in the root zone below an injurious level. The first step is to develop an irrigation system and method of applying water which will distribute it as uniformly as possible. Areas which chronically get less water than the rest of the orchard will be those in which salinity first builds up to damaging levels. The second step is to take soil samples at periodic intervals once or twice a year (fall of the year or spring and fall) depending upon the severity of the salinity problem. These samples should be taken from several locations throughout the orchard and by 1-foot increments to the full depth of the root zone. A simple analysis can be made on the saturation extract from the soil samples to determine the electrical conductivity and chloride concentration. Once every third or fourth sampling, the sodium and boron concentrations should also be measured. If the analysis shows that the concentrations are below damaging levels, there is no immediate concern. Presumably the normal irrigation program or winter rains have kept the salts washed out of the root zone. If the analysis shows that the concentrations are too high, the third step is to leach the salts out of the root zone by means of one or more extended irrigations. Leaching irrigations should be planned for the winter months when there may be some assist from winter rainfall and when the extended irrigations are less likely to damage the trees through excessive wetness or limitation of soil oxygen.

Microclimate Control

The modification of microclimate by irrigation is attempted either for protection against

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heat in the summer or against frost in the winter. Previous references have been made in this chapter to the possibility of hot spells and moisture stress causing excessive young fruit drop and reduction in growth. It is a well known fact to most citrus growers that early season heat waves can have devastating effects on their crops (Jones and Cree, 1965).

The possibility that sprinkler irrigation can protect the crop by humidifying and cooling the air during a heat wave has been considered by many growers and technical people. Some growers who possess over-tree sprinklers claim that sprinkling for several hours a day during abnormally warm periods has reduced the orchard temperature 10° F to 15° F and protected their crop so that yields for the year substantially exceeded those of their neighbors who did not have such cooling protection. However, reliable data on the effectiveness of cooling by overhead sprinkling are meager. Use of over-tree sprinklers for this purpose is limited to irrigation waters of low salt content to avoid salt injury from leaf absorption (page 266). Climatic conditions most conducive to salt damage are the same as those where cooling through sprinkling would be attempted.

Miller, Turrell, and Austin (1963) report a study where just three overhead sprinklers in a line spaced 54 feet apart were operated during the heat of the day in several tests. Climatic stations were established in and out of the sprinkled area to obtain measurements of the temperature and humidity. Wind measurements were also made. When midday temperatures rose above 90° F, operation of the three sprinklers lowered the temperature 4 to 6 degrees within the sprinkled area. When one of the sprinklers was moved to give an *L*-shaped placement rather than being in line, the temperature was lowered 6 to 8 degrees below that outside of the sprinkled area. It was assumed that sprinkling a large block would be more effective than just the small area possible in this test.

An unreplicated test was conducted by University of California extension and research personnel during 1962 in Tulare County where a 240-foot square block of trees was covered by sprinklers spaced in a 40-foot square pattern. Temperature reductions of 10° F were obtained in the sprinkled area when outside air temperatures were 100° F. Relative humidity rose from 25 to 50 per cent. With sprinklers on an 80-foot triangular spacing, only a 2° F temperature reduction was obtained.

Another citrus cooling study* in Kern County used overhead sprinklers with a precipitation rate of 0.2 inch per hour for irrigation and cooling. Cooling was accomplished by sequencing the sprinklers to operate five out of every fifteen minutes. Cooling was performed in May and June when "June drop" occurs. Temperature reductions of 15° F were obtained in the sprinkled area when the outside temperature was 103° F. The relative humidity increased 35 to 45 per cent in the sprinkled area compared to the outside fields. There was more fruit per tree in the cooled than in the non-cooled areas, but yield records are not available.

Irrigation has also been proposed as a frost protection measure for citrus. This might be done either by surface or sprinkler irrigation. On a cold night, heat radiates from the leaves and fruit of the tree, and from the soil surface and is lost by radiation to the cold sky. A cold wind also depletes large quantities of heat. Because a wet soil has both a greater heat capacity and heat conductivity than a dry soil, surface irrigation could increase the ability of the soil to radiate its heat, much of which might be intercepted by the tree. If irrigation water is appreciably warmer than the soil, the heat input would be helpful.

Turrell, Austin, and Perry (1961) reported that furrow irrigation for one hour with water at 70° F on a night of about 29° F minimum orchard temperature produced warming by a net radiation upward into the tree canopy lasting about four hours. Leaf temperature was increased slightly. In the winter of study, freeze damage was less severe to the entire orchard than in previous years possibly because it had been better irrigated and the trees were not so dry. Hilgeman, Everling, and Dunlap (1964) reported on a study made on a cold night in January, 1962. Wind machines, orchard heaters, and flood irrigation from 9 P.M. to 5 A.M. were used. Temperature measurements at 5 feet between 5 and 7 A.M. showed minimum temperatures from 20° to 21° F in the control area, from 22° to 23° F in the separate wind machine area, from 23° to 25° F in the combined wind machine and heater area, and from 24° to 26° F in the wind machine-irrigated area.

Sprinkler irrigation has been used for frost protection in various areas for vegetables and berries and has been tried to some extent in citrus.

* Report to Kern County irrigation distributors and dealers by F. K. Aljibury, 1971.

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During the hard freezes of 1962–63, sprinkler irrigation on citrus was attempted in Florida, southern California, and the San Joaquin Valley of California. Miller (1963) reported a study of sprinklers operated during the freezing weather of January, 1963, and noted that wet-bulb temperatures play an important part in the effectiveness of sprinklers for frost protection. The use of sprinklers during periods of low humidity and therefore low wet-bulb temperature will lower the temperature in the orchard during those periods when the atmospheric temperatures are still above freezing. Icicles actually formed when the air temperature was 35° F. Miller noted that sprinklers have less opportunity to be effective as a frost protection measure under these conditions and if they are used must be kept running until the wet-bulb temperature has risen above freezing or until the ice has melted from the tree. If the sprinklers are stopped before the ice has all melted from the trees, the ice on the trees approaches the wet-bulb temperature rather than the dry-bulb temperature.

Norris (1963) found that protection against the severe freezes occurring in Florida during the winter of 1962–63 required a precipitation rate of 0.3 inch per hour. Trees kept under constant precipitation at this rate were effectively protected. Where wind interfered with the distribution, the protection was spotty. Limb breakage from the ice load was serious, but total damage was less than for those trees in adjoining, unwatered groves. He noted that the 0.3 inch per hour precipitation rate which gave the protection was three times higher than the rate most cold protection systems were using. Groves which were sprinkled at 0.1 inch per hour, the commonly used rate, suffered worse damage than adjacent unwatered groves. Norris believes that sprinkling cannot as yet be a general recommendation for frost protection.

Gerber and Harrison (1964) after a theoretical, laboratory, and field study stated that irrigation can be used successfully for cold protection if sufficient water is used. In test chambers, sprinkling with sufficient water protected trees at air temperatures of 20° F with wind speeds of 10 mph. Since the killing temperature for wet sweet orange leaves is about 4° F higher than for dry leaves (24° vs 20° F), and deficient sprinkling allows the leaf to assume the wet-bulb temperature, deficient sprinkling increases cold damage.

Any use of irrigation for modifying the microclimate must consider the effect water will have on soil in the root zone of the trees. Excessive water on soils of poor drainability might cause more damage in some cases than the adverse weather condition which the irrigation is trying to combat. With porous, well-drained soils there should be no problem. With fine-textured, slowly drained soils, the grower should be aware of the hazards which might arise. As previously explained, excess wetness in the soil will probably be less damaging during winter than it would be in summer; therefore, sprinkling for frost protection does not present quite as much hazard to the tree roots as sprinkling for high temperature control.

DESIGN OF THE IRRIGATION SYSTEM

The design of the irrigation system should be accomplished before the citrus orchard is laid out and planted, for it will influence the orchard layout. Once an orchard has been set out there are limitations on the type of system that can be used and on the proper installation.

Choosing Type of System

Initially, the grower must choose the type of system to be used. The selection should be based on an analysis of the physical conditions existing, supplemented by an economic analysis. Personal feelings are often important in the choice, but should be subordinated to the physical and economic analysis. In the United States, assistance in obtaining physical data and making the analyses are generally available from the Agricultural Extension Service or the U. S. Soil Conservation Service.

The first step in physical analysis is to obtain a survey of the area to be planted to citrus. This survey should show the slope and topography of the land, the soil types found, and the areas occupied by each soil type. The nature of the water supply, its quality, and its method of delivery also affect the choice, as described earlier. The characteristics and capacity of each soil type for infiltrating and storing irrigation water should be determined. If the soil areas differ appreciably, the irrigation system should be planned so that the different soil types can be irrigated independently.

When the physical analysis has narrowed the field of acceptable systems based on the considerations discussed earlier on page 299 under "Methods of Irrigation," an economic analysis is useful for the final choice. If the choice remains between a surface and a sprinkler system, the

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cost of land preparation needed for a surface method of application must be considered and will help offset the higher equipment cost of a sprinkler system. There may also be differences in the cost of preparing land for different surface methods of irrigation. In any comparison of irrigation methods, an estimate of the labor cost to apply the water and service the equipment is needed. One method having higher initial cost for equipment and/or land preparation may have enough lower labor cost to make it an economic choice over a method having lower initial cost. This comparison should be used not only between surface and sprinkler methods, but between different surface methods, different sprinkler methods, or between different degrees of equipping either a surface or sprinkler system. Drip irrigation should also be compared in the same manner.

Professional Design Desirable

When the type of system has been selected by a physical and economic analysis, the actual engineering design must be made. For this purpose, it is desirable to employ a professional engineer or irrigation system designer. An irrigation system will be an expensive installation, and money spent for a professional design is well worthwhile. The professional designer can make engineering calculations which will insure adequate capacity in all the pipes and components so that the grower will not be frustrated in his effort to provide adequate water when peak demands arise. He can also avoid over-designing so that the system need not be excessively expensive, but will be efficient in its total operation.

Having employed a professional system designer, the grower must provide him with the specifications around which he wants the system designed. These will include the physical data, economic calculations, and the grower's desires.

The physical data needed are those previously stated and information on the expected water requirement. The latter information may be available from publications such as Pillsbury *et al.* (1944), where the actual irrigation requirement of citrus has been measured for a particular area. If citrus has already been grown in the area, a reasonable estimate of water requirement can be obtained from the water-use records of other growers. If no previous records are available for the area, an estimate can be made from weather station data using a formula such as that devised by Blaney and Criddle (1962).

In addition to the physical data, the grower should inform the designer about his own personal desires and what he expects from a system. This will include his decisions derived from the economic analysis about the degree of expenditure for equipment to reduce the labor requirement, the type of lines, the type of surface delivery mechanisms, the type of sprinklers, the planting plan, and desired uniformity of distribution and precipitation rate.

Uniform distribution of irrigation water is one of the most important objectives in the design and operation of an irrigation system. The degree of uniformity of water distribution which the grower wishes to attain should be plainly stated to the designer. A common rule of thumb utilized by irrigationists to obtain reasonably uniform distribution with surface irrigation states that all portions of the ground which are to be covered with water should be covered for at least 75 per cent as long a time as those portions first receiving water. If a furrow irrigation is to be applied for 24 hours, the water should reach the lower end of the run within 6 hours after starting. Correspondingly, a rule used in sprinkler-irrigation design states that the difference in pressure at the nozzles of any two sprinklers on an irrigation line shall not exceed 20 per cent of the highest nozzle pressure on the line. The design should permit adherence to these rules.

The precipitation rate of sprinklers must be lower than the minimum infiltration capacity of the soil, or there will be run-off, causing poor distribution and possibly serious soil erosion. Infiltration capacity and its changes are described on page 234. While precipitation rates as high as 1 inch per hour can be used on deep sandy soils, this requires frequent moves and high volume flows in pipelines. The trend is toward lower precipitation rates with smaller pipes and longer sets. Rates of $\frac{1}{4}$ to $\frac{1}{3}$ inch per hour are common on coarse- and medium-textured soils and permit convenient runs of 12 hours. On medium- to fine-textured soils, rates between $\frac{1}{10}$ and $\frac{1}{4}$ inch per hour are used with sets lasting 24 hours.

The type of distribution lines will need to be decided. Most citrus orchards in the southwestern United States having surface irrigation use underground concrete pipe systems for delivering water to the head of each run. Concrete pipe is not adapted for delivering silty water at low velocity nor for high pressures, unless the

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pipe is adequately reinforced. Compared with open-ditch delivery systems, underground concrete pipe eliminates waste land, reduces waste of water, permits more closely regulated flows of water, and reduces the weed problem. A good quality concrete pipe should be used and is generally available in most localities. Asbestos concrete pipe (ACP) is also used. This type of pipe is more expensive initially than the concrete, but because it offers less friction resistance to the flow of water, a smaller size can frequently be used. It is also capable of handling higher pressures than concrete pipe, a feature necessary with sprinkler irrigation. It is available in sizes down to 3-inch diameter. For lateral lines with sprinkler irrigation, aluminum and steel have been used, but recent installations have included increasing amounts of plastic pipe (PVC), particularly where the lines are to go underground. Assembly is relatively simple and corrosion, which reduces flow capacity with time, is nonexistent. Sizes are available from ½-inch to 6-inch diameter and possibly larger.

When the grower has provided the designer with the necessary information and specifications, he expects and should get an irrigation system which will operate to his satisfaction with the highest possible efficiency. However, it will operate at its potential efficiency only if the grower operates it in the manner set forth by the designer. Unsatisfactory operations of irrigation systems, particularly sprinkler systems, have been encountered where the grower altered the system from that developed by the designer.

Land Preparation

Land preparation follows the irrigation system design. If a sprinkler system is selected, there may be little or no land preparation needed, depending on previous use and vegetative cover. If an orchard is to be developed from unused brush-covered land, frequently of rolling to hilly terrain, some preparation will be needed. This will involve brush removal, a smoothing of sharp crevices or humps, and possibly a deep ripping or subsoiling operation.

If a surface irrigation system is to be used, the design will usually indicate what land grading and preparation are required. A good design will usually minimize the amount of soil to be moved in establishing satisfactory grades. Unless the soil depth is fairly great, the moving of too much soil would create spotted conditions within a field and the trees will respond accordingly. The selection of land for citrus growing is often based on minimizing frost hazards, which may mean that the land is sloping or rolling. Soil in such positions is more inclined to be shallow than deep, and removal of large amounts in land grading cannot be tolerated.

A uniform grade of sufficient slope to move the water satisfactorily from the top to the bottom of the run is desirable in most cases. Various degrees of grade are possible, depending upon the system of water distribution employed. Flatter grades are desirable for border irrigation, and somewhat steeper grades can be tolerated with furrow irrigation. If the slope is too steep, a system of contour furrows should be used which will provide a moderate, but uniform grade from the top to the bottom of the run. A system of land grading creating level or slightly graded terraces on successive benches is occasionally used in the U. S., but more commonly in Japan, Spain, and Italy. With a level bench, a basin system of irrigation is used. Furrow irrigation would be applied to graded terraces.

Drainage

Citrus has low tolerance for a water table in or near the root system. The roots are severely damaged by excessive wetness, which would prevail immediately above a water table, and are killed in a short time by being submerged under a water table, particularly in hot weather. In arid lands, the presence of a water table in or near the root zone is likely to interfere with effective leaching and lead to salt concentration (see p. 272). Where salt hazards exist, citrus must be grown on well-drained soil in which the water table will not rise closer than 5 or 6 feet to the soil surface.

If a choice exists, citrus should be grown only on naturally well-drained soils. Since this is not always possible, some concern must be given to drainage management.

Some soils infiltrate water readily, but have a natural drainage slower than the infiltration capacity. Excessive irrigation may create a temporary water table in the root zone of sufficient duration to damage the trees. Such a situation can sometimes be controlled by revision of irrigation practices. If not, artificial drainage is needed. The need for leaching salts sometimes makes excess irrigation mandatory. Natural drainage may be sufficient to prevent the water table from rising into the root zone. If not, artificial drainage is needed. In some places, the water table may rise

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and fall because of irrigation practices and conditions prevailing in adjacent lands over which the citrus grower has no control. Where this occurs, artificial drainage is definitely needed.

If the need for artificial drainage is anticipated from a knowledge of surrounding conditions when an orchard is established, a drain system should be planned and installed at the same time the land is prepared and the irrigation system built. Tile or covered drains are preferred for citrus because of the problems of maintenance and weed control, and because valuable land is lost with open drains. If water from adjacent land is the principal cause of the high water table, an interceptor drain along the property boundary may be sufficient. Expert advice and engineering assistance is recommended before installing an artificial drain system.

Need for drainage in the future cannot always be anticipated, and the installation of a drainage system where there is no apparent need is a sizeable expenditure in which the grower will not wish to indulge at the time of establishing his orchard. It would be prudent for the grower to make periodic observations by means of auger holes or piezometers[a] after the orchard is established to learn if a water table has developed so that corrective steps can be taken before damage to the trees occurs. If artificial drainage is needed it can be installed in a growing orchard. If there is no water table, a tile drain will be ineffective (see p. 235).

LITERATURE CITED

BALL, J. 1952. Contribution to the geography of Egypt. [Egypt] Min. Finance and Econ. 308 pp.

BENTON, R. J. 1943*a*. Water needs of citrus trees. Citrus News 19(1):6–7.

——— 1943*b*. Irrigation needs of citrus trees. Citrus News 19(2):38–39.

BEUTEL, J. A. 1964. Soil moisture, weather and fruit growth. Cailf. Citrog. 49:372.

BIALOGLOWSKI, J. 1937. Effect of extent and temperature of roots on transpiration of rooted lemon cuttings. Proc. Amer. Soc. Hort. Sci. 34:96–102.

BLACK, A. P., and E. BROWN. 1951. Chemical character of Florida's waters. Div. Water Surv. and Res., Fla. State Board of Conserv., Water Surv. Res. Pap. No. 6:114–18.

BLANEY, H. F., and W. D. CRIDDLE. 1962. Determining water requirements, consumptive use and irrigation. U. S. Dept. Agr. Tech. Bul 1275:59 pp.

BOWER, C. A., and F. B. GSCHWEND. 1952. Ethylene glycol retention by soils as a measure of surface area and interlayer swelling. Soil Sci. Soc. Amer. Proc. 16:342–45.

CAHOON, G. A., R. B. HARDING, and D. B. MILLER. 1956. Declining citrus root systems. Calif. Agr. 10:3, 12.

CAHOON, G. A., M. R. HUBERTY, and M. J. GARBER. 1961. Irrigation frequency effects on citrus root distribution and density. Proc. Amer. Soc. Hort. Sci. 77:167–72.

CAHOON, G. A., and L. H. STOLZY. 1959. Estimating root density and distribution in citrus orchards by the neutron moderation method. Proc. Amer. Soc. Hort. Sci. 74:322–27.

——— 1960. Citrus root density in relation to water use. Calif. Citrog. 45:318, 323.

CAHOON, G. A., L. H. STOLZY, M. J. GARBER, and E. S. MORTON. 1964. Influence of nitrogen and water on the root density of mature Washington navel orange trees. Proc. Amer. Soc. Hort. Sci. 85:224–31.

CAHOON, G. A., L. H. STOLZY, E. S. MORTON, and T. E. SZUSZKIEWICZ. 1957. Buying root insurance. Citrus Leaves 37(7):6–7, 18.

CHAPMAN, H. D. 1950. Citrus leaf analysis. Calif. Agr. 3:10, 12, 14.

COE, J. J., and F. S. FLORIAN. 1957. Quality of surface and groundwaters in upper Santa Ana Valley. Calif. Dept. Water Res. Bul. 40–57: 140 pp.

COOPER, W. C., and A. V. SHULL. 1953. Salt tolerance of and accumulation of sodium and chloride ions in grapefruit on various root stocks grown in a naturally saline soil. Rio Grande Val. Hort. Inst. Proc. 7:107–17.

CORE, E. J. 1951. Border irrigation. U. S. Dept. Agr. Leaf. 297: 8 pp.

CURTIS, D. S. 1949. Effect of oxygen supply in nutrient solution on avocado and citrus seedlings. Soil Sci. 67:253–60.

DEWOLFE, R. H. 1962. Coachella grower adopts new sprinkler system. Western Fruit Grow. 16(3):45.

EATON, F. M. 1944. Deficiency, toxicity and accumulation of boron in plants. Jour. Agr. Res. 69:237–77.

EATON, F. M., and R. B. HARDING. 1959. Foliar uptake of salt constituents of water by citrus plants during intermittent sprinkling and immersion. Plant Physiol. 34:22–26.

EHLIG, C. F., and L. BERNSTEIN. 1959. Foliar absorption of sodium and chloride as a factor in sprinkler irrigation. Proc. Amer. Soc. Hort. Sci. 74:661–70.

ERICKSON, L. C., and S. J. RICHARDS. 1955. Influence of 2,4-D and soil moisture on size and quality of Valencia oranges. Proc. Amer. Soc. Hort. Sci. 65: 109–12.

[a] For this purpose, a piezometer can be considered as a 1-inch auger hole of 8 or 9 feet depth in which a ½-inch pipe is inserted to facilitate repeated measurements of water table depth. The pipe extends slightly above ground surface and is capped to prevent filling with debris.

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FURR, J. R. 1955. Responses of citrus and dates to variations in soil water conditions at different seasons. XIV Intern. Hort. Cong. Rept. [Netherlands] 1: 400–12.

FURR, J. R., and C. A. TAYLOR. 1934. The cross-transfer of water in mature lemon trees. Proc. Amer. Soc. Hort. Sci. 30:45–51.

——— 1939. Growth of lemon fruits in relation to moisture content of the soil. U. S. Dept. Agr. Tech. Bul. 640: 71 pp.

GERBER, J. F., and D. S. HARRISON. 1964. Sprinkler irrigation for cold protection of citrus. Trans. Amer. Soc. Agr. Eng. 7(4):464–68.

GIRTON, R. E. 1927. The growth of citrus seedlings as influenced by environmental factors. Univ. Calif. Pubs. Agr. Sci. 5:83–117.

HALMA, F. F. 1934. Some phases in the water relation of citrus. Proc. Amer. Soc. Hort. Sci. 31:108–09.

——— 1935. Trunk growth and the water relation in leaves of citrus. Proc. Amer. Soc. Hort. Sci. 32:273–76.

HAMMOND, L. C. 1956. Can irrigation lessen citrus fruit drop? Citrus Indus. 37:8, 18.

HARDING, R. B., M. G. MILLER, and M. FIREMAN. 1958. Absorption of salts by citrus leaves during sprinkling with water suitable for surface irrigation. Proc. Amer. Soc. Hort. Sci. 71:248–56.

HARDING, R. B., P. F. PRATT, and W. W. JONES. 1958. Changes in salinity, nitrogen and soil reaction in a differentially fertilized irrigated soil. Soil Sci. 85: 177–184.

HENDRICKSON, A. H., and F. J. VEIHMEYER. 1931. Influence of dry soil on root extension. Plant Physiol. 6:567–76.

HILGEMAN, R. H. 1956. New irrigation plan for orange trees. Calif. Citrog. 41:455.

HILGEMAN, R. H., C. E. EVERLING, and J. A. DUNLAP. 1964. Effect of wind machines, orchard heaters and irrigation water on moderating temperatures in a citrus grove during severe freezes. Proc. Amer. Soc. Hort. Sci. 85:232–44.

HILGEMAN, R. H., and L. H. HOWLAND. 1955. Fruit measurements and tensiometers can tell you when to irrigate citrus trees. Progr. Agr. Arizona 7(1): 10–11.

HILGEMAN, R. H., and D. R. RODNEY. 1961. Commercial citrus production in Arizona. Ariz. Agr. Expt. Sta. Ext. Serv. Special Rpt. 7: 31 pp.

HILGEMAN, R. H., and G. C. SHARPLES. 1957. Irrigation trials with Valencias in Arizona. Calif. Citrog. 42: 404–07.

HILGEMAN, R. H., and C. W. VAN HORN. 1954. Citrus growing in Arizona. Ariz. Agr. Expt. Sta. Bul. 258: 35 pp.

HUBERTY, M. R. 1948. Principles and methods of irrigation. *In:* Batchelor, L. D., and H. J. Webber (eds.). The citrus industry, II:445–93. Univ. Calif. Press, Berkeley and Los Angeles.

HUBERTY, M. R., and S. J. RICHARDS. 1955. Irrigation experiments with navel oranges at the Citrus Experiment Station, Riverside. Univ. Calif. Dept. Irrig. and Soils, Los Angeles and Riverside. 7 pp. (Mimeo.)

JOHNSTON, J. C. 1953. Citrus growing in California. Calif. Agr. Expt. Sta. Circ. 426: 43 pp.

JONES, W. W. and C. B. CREE. 1965. Environmental factors related to fruiting of Washington navel oranges over a 38-year period. Proc. Amer. Soc. Hort. Sci. 86:267–71.

KLOTZ, L. J., and T. A. DEWOLFE. 1959. Twig dieback of citrus. Calif. Citrog. 44:99–100.

KLOTZ, L. J., T. A. DEWOLFE, L. C. ERICKSON, L. B. BRANNAMAN, and M. J. GARBER. 1962. Twig dieback of citrus trees. Calif. Citrog. 47:74, 86, 88, 90–91.

KOO, R. C. J. 1961. The distribution and uptake of soil moisture in citrus groves. Proc. Fla. State Hort. Soc. 74:86–90.

KOO, R. C. J. 1963. Effects of frequency of irrigations on yield of orange and grapefruit. Proc. Fla. State Hort. Soc. 76:1–5.

KOO, R. C. J., and J. W. SITES. 1955. Results of research and response of citrus to supplemental irrigation. Soil Sci. Soc. Fla. Proc. 15:180–90.

KURAOKA, T., K. MATSUMOTO, T. KIKUCHI, and J. WATANABE. 1957. Fundamental investigations on the irrigation of citrus trees. Jour. Hort. Assoc. Jap. 26: 83–94.

LETEY, J., L. H. STOLZY, N. VALORAS, and T. E. SZUSZKIEWICZ. 1963. Low soil oxygen most damaging to plants during hot weather. Calif. Agr. 17:15.

LOMBARD, P. B., L. H. STOLZY, M. J. GARBER, and T. E. SZUSZKIEWICZ. 1965. Effects of climatic factors on fruit volume increase and leaf water deficit of citrus in relation to soil suction. Soil Sci. Soc. Amer. Proc. 29:205–08.

LUTZ, J. F. 1965. Chairman Terminology Committee, SSSA, 1965. Soil Sci. Soc. Amer. Proc. 29:330–51.

LYON, A. V. 1958. Irrigation frequencies should be re-examined in dry periods in light of need for earlier or extra waterings. Citrus News 34:9.

MARR, J. C. 1954. The border method of irrigation. Calif. Agr. Expt. Sta. Circ. 408: 23 pp.

MARSH, A. W. 1958. Irrigation practices and problems. Calif. Citrog. 44:44, 54–59.

MARTIN, J. P., R. B. HARDING, and M. J. GARBER. 1961. Relation of soil properties and plant composition to growth of citrus seedlings in 100 nonfumigated and fumigated old citrus soils. Soil Sci. 91(5):317–23.

MENDEL, K. 1945. Orange leaf transpiration under orchard conditions. 2. Soil moisture decreasing. Agr. Res. Sta. [Rehovot] Bul. 37:59–85.

MILLER, M. P. 1963. Sprinklers and frost protection. Calif. Citrog. 48:267, 277–78.

MILLER, M. P., F. M. TURRELL, and S. W. AUSTIN. 1963. Cooling avocado trees by sprinkling. Calif. Agr. 17:4–5.

NIR, N. 1964. Salinity survey progress report for 1963. State of Israel, Min. of Agriculture, Water Commissioner's Office, Tel Aviv, May 1964. 93 pp.

NORRIS, R. E. 1963. Thermo-irrigation in Florida. Calif. Citrog. 48:326–28.

OPPENHEIMER, H. R., and D. L. ELZE. 1941. Irrigation of citrus trees according to physiological indicators. Agr. Res. Sta. [Rehovot] Bul. 31: 28 pp.

PEARSON, H. E., and M. R. HUBERTY. 1959. Response of citrus to irrigation with water of different chemical characteristics. Proc. Amer. Soc. Hort. Sci. 73:248–56.

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PENMAN, H. L. 1950. Evaporation over the British Isles. Quart. Jour. Roy. Meteorol. Soc. 76:372.

PILLSBURY, A. F., O. C. COMPTON, and W. P. PICKER. 1944. Irrigation-water requirements of citrus in the south coastal basin of California. Calif. Agr. Expt. Sta. Bul. 686: 19 pp.

PUFFER, R. E. 1962. Citrus notes. Agr. Ext. Serv., San Bernardino Co., Calif. 2 pp.

REED, H. S., and E. T. BARTHOLOMEW. 1930. The effects of desiccating winds on citrus trees. Calif. Agr. Expt. Sta. Bul. 484: 59 pp.

REEVE, J. O., and J. R. FURR. 1941. Evaporation from a shallow black pan evaporimeter as an index of soil moisture extraction by mature citrus trees. Proc. Amer. Soc. Hort. Sci. 39:125–32.

REUTHER, W., and C. L. CRAWFORD. 1946. Effects of certain soil and irrigation treatments on citrus chlorosis in a calcareous soil: I. Plant responses. Soil Sci. 62:477–91.

——— 1947. Effect of certain soil and irrigation treatments on citrus chlorosis in a calcareous soil: II. Soil atmosphere studies. Soil Sci. 63:227–40.

RICHARDS, L. A. 1950. Laws of soil moisture. Amer. Geophys. Union Trans. 31:750–56.

RICHARDS, L. A., and M. R. HUBERTY. 1941. Moisture studies under citrus using tensiometers. Proc. Amer. Soc. Hort. Sci. 39:73–79.

RICHARDS, S. J., and R. M. HAGAN. 1958. Soil moisture tensiometer. Calif. Agr. Expt. Sta. Leafl. 100: 3 pp.

RICHARDS, S. J., and M. R. HUBERTY. 1956. Use of tensiometers in the irrigation of citrus. Proc. Amer. Soc. Hort. Sci. 67:210–14.

RICHARDS, S. J., and A. W. MARSH. 1961. Irrigation based on soil suction measurements. Soil Sci. Soc. Amer. Proc. 25:65–69.

RICHARDS, S. J., L. V. WEEKS, and L. C. ERICKSON. 1961. Water use by lemon trees in relation to soil compaction and tree growth. Soil Sci. 92:347–50.

RICHARDS, S. J., L. V. WEEKS, and J. E. WARNEKE. 1960. Compacted bulk density and hydraulic conductivity for indicating the structural status of soil. Intern. Cong. Soil Sci. (7th) Trans. 1:249–55.

SAMISH, R. M. 1957. Irrigation requirement of a young citrus orchard. Ktavim 7:2–3, 123–39.

SMITH, G. E. P., A. F. KINNISON, and A. G. CARNS. 1931. Irrigation investigations in young grapefruit orchards on the Yuma-Mesa. Ariz. Agr. Expt. Sta. Tech. Bul. 37:413–591.

SPURLING, M. B. 1950. Water requirements of citrus. Dept. Agr. So. Austral. Bul. 419: 19 pp.

STOLZY, L. H. 1960. Citrus adjusts to new water schedule. Crops and Soils 12:28.

STOLZY, L. H., G. A. CAHOON, and T. E. SZUSZKIEWICZ. 1957. Measurement of soil moisture. Calif. Agr. 11:21–22, 37.

STOLZY, L. H., J. LETEY, L. J. KLOTZ, and T. A. DEWOLFE. 1965. Soil aeration and root-rotting fungi as factors in decay of citrus feeder roots. Soil Sci. 99:403–06.

STOLZY, L. H., A. W. MARSH, R. E. PUFFER, and D. C. BAIER. 1960. Placement of tensiometers as guides to irrigation practices. Calif. Agr. 14:11–12.

STOLZY, L. H., P. W. MOORE, L. J. KLOTZ, and T. A. DEWOLFE. 1959. Growth rates of orange seedlings in the presence and absence of phytophthora spp. at two levels of irrigation and two levels of soil nitrogen. Plant Dis. Rept. 43:1169–73.

STOLZY, L. H., O. C. TAYLOR, M. J. GARBER, and P. B. LOMBARD. 1963. Previous irrigation treatments as factors in subsequent irrigation level studies in orange production. Proc. Amer. Soc. Hort. Sci. 82: 199–203.

TAYLOR, C. A. 1939. Irrigation problems in citrus orchards. U. S. Dept. Agr., Div. Irrig., Bur. Agr. Eng. 15 pp. (Mimeo.)

——— 1941. Irrigation problems in citrus orchards. U. S. Dept. Agr. Farmer's Bul. 1876:34.

TAYLOR, S. A., D. D. EVANS, and W. D. KEMPER. 1961. Evaluating soil water. Utah Agr. Expt. Sta. Bul. 426: 67 pp.

THOMAS, E. E. 1922. Studies on the irrigation of citrus groves. Calif. Agr. Expt. Sta. Bul. 341:353–70.

TRUMBLE, H. P. C. 1952. Improved irrigation programmes for citrus. Jour. Dept. Agr. So. Austral. 56:133–39.

TURRELL, F. M., S. W. AUSTIN, and R. L. PERRY. 1961. Water, heaters and wind machines. Calif. Citrog. 46:154, 156, 158, 160.

U. S. SALINITY LABORATORY. 1954. Diagnosis and improvement of saline and alkali soils. U. S. Dept. Agr. Handbook 60: 160 pp.

VAILE, R. S. 1924. A survey of orchard practices in the citrus industry of southern California. Calif. Agr. Expt. Sta. Bul. 374: 40 pp.

VAN BAVEL, C. H. M., J. E. NEWMAN, and R. H. HILGEMAN. 1966. Climate and estimated water use by an orange orchard. Agr. Meteor. 126:1–13.

WANDER, I. W., and H. J. REITZ. 1951. The chemical composition of irrigation water used in Florida citrus groves. Fla. Agr. Expt. Sta. Bul. 480: 22 pp.

WEDDING, R. T., and L. C. ERICKSON. 1960. Water stress and leaf drop. Calif. Agr. 14:7.

WILCOX, L. V. 1955. Classification and use of irrigation waters. U. S. Dept. Agr. Circ. 969: 19 pp.

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CHAPTER 9

Climate and Citrus Behavior

WALTER REUTHER

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WORLD CITRUS PRODUCTION during the past century has grown from less than one million tons to about 32 million tons in 1970–71 (Schuler, Todd, and Scarborough, 1971). This expansion was concurrent with the discovery and development of vast new areas adapted to citrus culture in many parts of the world, especially in Africa, Australia, and the Americas. For the most part, these new areas were delineated empirically by trial and error on the part of practical orchardists; it is only during the past three or four decades that we have acquired sufficient knowledge and climatic data to have even limited success in predicting the probable adaptation of citrus to a new area. In addition, we have recently come to recognize some of the special climatic requirements of particular varieties and species. For example, we have learned that such orange and orange-like varieties as Washington navel, Shamouti, and Temple have rather specialized, narrow climatic requirements from a horticultural viewpoint, whereas Valencia is adapted to a relatively wide climatic range. Similarly, the grapefruit, pommelo, lemon, and lime groups each develop best production and market quality within somewhat different climatic parameters. Within a species or group, mandarin and mandarin-like varieties exhibit perhaps the widest diversity from narrow- to broad-spectrum adaptations to climate.

In semiarid subtropical citrus-growing regions, exemplified by the southwestern United States and many countries bordering the Mediterranean Sea, supplemental irrigation is essential to the commercial crop culture, and indeed, even to its survival. In other subtropical areas, such as the southeastern United States, some parts of Japan, subtropical and tropical Asia, Oceania, Africa, Australia, and Central and South America, commercial citrus culture is feasible without supplemental irrigation. Perhaps the greater portion of the world's commercial citrus-producing areas, however, cannot maintain satisfactory commercial production with natural rainfall alone, and must utilize some form of supplemental irrigation.

Most cultivated citrus trees in the higher subtropical latitudes and in the higher altitudes of the lower subtropical latitudes are damaged periodically by freezes. Within the last several decades, heating and other reasonably effective protective techniques have been developed (see chap. 10), and are now widely used in the more advanced high frost hazard regions.

Studies concerned with the influence of bioclimatic factors on citrus mostly have emphasized two main areas. The first is susceptibility to freezing injury and its nature and causes. This is quite natural, because this aspect of the adaptation of citrus varieties and species to climate is of primary importance in delineating the areas where they can be grown successfully as a commercial crop. It is also natural because unusually severe freezes have, at rare intervals, virtually wiped out hundreds of thousands or even millions of cultivated citrus trees in certain areas. At more

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frequent intervals, freezes have caused severe crop losses associated with varying degrees of temporary tree damage (see chap. 10). The second factor is the influence of climatic phenomena on transpirational use of water by citrus trees and on their soil moisture requirements. The high priority given this area of inquiry was and is supported by the obvious relation of vigor, productivity, and fruit quality to soil moisture availability in arid regions (see chap. 8).

The effects of climate, and especially of energy-related factors, on major growth and development processes of citrus plants have been somewhat neglected so far. The effects of diurnal and seasonal regimes of temperatures, humidity, wind movement, radiation, and day length are still poorly understood, though they undoubtedly strongly influence the observed differences in adaptation and behavior of specific varieties in different climatic zones. The low priority that this area of investigation has been accorded until now is probably due primarily to its inherently complex and interdisciplinary nature, and to the limited possibilities for climate modification under orchard conditions.

However, rapid progress is now being made in the field of agricultural climatology. The availability of highly sophisticated new tools such as new and improved instrumentation, elaborate controlled environment facilities, and computers for mass data processing, give promise that the next two or three decades will see great advances in our knowledge of the relation of physical environment to plant behavior and varietal adaptation. Citrus should prove to be an excellent subject for such studies because of both its great economic importance in many countries and its observed sensitivity to seemingly minor climatic differences.

This chapter is an effort to summarize the limited knowledge available concerning bioclimatic influences, especially energy-related ones, on vegetative growth, yield, flower biology, fruit set, fruit growth and maturation, physical and chemical characters of fruit, and related metabolic and developmental processes in the genus *Citrus*.

SOME BROAD CLIMATIC CONSIDERATIONS

World Distribution and Potentials

The large-scale, commercial exploitation of citrus species, not only for shipment as fresh fruit to distant markets but also for the manufacture of industrial products, has developed almost exclusively in subtropical regions. These occur largely in two major belts around the world extending roughly between 20 and 40 degrees north and south of the equator. Though citrus is probably native to tropical Southeast Asia (Webber, Reuther, and Lawton, 1967) it has not yet been exploited on an extensive scale in the largely tropical belt centered on the equator and lying between the two subtropical belts. Citrus species are, however, widely grown in tropical regions as a home garden or small orchard crop for local sale. The reasons for this pattern of world distribution of citrus culture involve not only plant adaptation factors, but human ones as well. The latter include historical, cultural, political, health, and technological factors which cannot be considered here. The plant factors will be touched on in later sections.

Most, but not all, cultivated citrus species and varieties produce fruit of better market appeal in an environment that is more subtropical than tropical in nature. This may be due largely to the fact that most cultivated varieties have been selected in subtropical regions for adaptation to subtropical climates. Also the highest production levels currently are achieved, in general, in regions where there is a well-defined cold-induced dormancy period. In a Mediterranean-type subtropical climate such as that in southern California most, but not all, citrus species normally bloom heavily in the February–April period (August–October in the southern hemisphere). This spring bloom accounts for virtually the entire crop in most years. It is normally preceded by a cool period of two to four months in duration with sufficient chilling weather to induce complete dormancy.

Observations and some data in tropical regions indicate that the lack of a sharply contrasting warm-cool temperature seasonality is associated with everbearing types of fruiting habits in most citrus species (Mendel, 1969; Cassin *et al.*, 1969; Reuther and Rios-Castaño, 1969) when precipitation is adequate and well distributed. Perhaps this is due more specifically to absence or scarcity of appreciable chilling periods with air and/or soil temperatures below the threshold which induces dormancy. In tropical areas with a well-defined annual period (or periods) of low-rainfall, a sustained moisture stress appears to substitute for chilling in producing a dormancy associated with flower induction and subsequent blooming (Chandler, 1958; Cassin *et al.*, 1969; Torres-M. and Rios-Castaño, 1968; Bain, 1949;

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Fig. 9–1. Range of size of fruit picked from a single Valle de Cauca navel orange tree at the Instituto Colombiano Agropecuario, Palmira, Colombia in June. Fruits range from 1 to 7 cm in diameter, are estimated to be from 1.5 to 7 months from anthesis, and represent eight distinct blooms. The fruit on the extreme right is pale yellow in color and all the rest are dark green.

Reuther and Rios-Castaño, 1969). Thus, the cropping pattern may become complex in the tropics. With a well distributed year-around soil moisture supply, six to eight distinct crops or maturity classes of oranges, for example, can be distinguished on a tree at one time (fig. 9–1). Usually, however, most orange varieties set one or two major crops and one or two minor crops per year in tropical regions, depending largely on the rainfall distribution pattern. Observations and limited records indicate that consistently heavy yields of 16 to 18 tons per acre (36 to 40 tons/ha) common in subtropical regions (Savage, 1968) in mature orange orchards are not common in tropical regions. Yields do not appear to attain commonly more than 6 to 10 tons per acre (13 to 22 tons/ha) in the tropics.

Whether climate is always a primary yield-limiting factor for citrus culture in tropical regions is an open question. Locally developed research information on fertility, irrigation, plant protection, and related cultural problems is for the most part lacking in tropical areas. Also, there has been little selection of varieties specifically adapted to tropical conditions. Hence, it has not been possible so far to evaluate the yield potential of citrus in such areas under optimal cultural conditions providing adequate control of soil moisture and fertility, and good protection against pests and diseases. During travels and surveys, the author has encountered great vigor and heavy production only in a few exceptional orchards in the tropics. When located on very fertile, deep, well-drained soils which maintain appropriate soil moisture regimes through rainfall or supplemental irrigation, and which follow effective pest and disease control and other cultural practices, orchards may have a yield potential even greater in tropical than in subtropical regions.

Indeed, data from tropical Colombia (Rios-Castaño, Torres-M., and Camacho-B., 1968) reporting yields on young orange trees from 12 to 17.5 tons per acre (27 to 39 kg/ha) suggest this is so. These yields were obtained in experimental plantings of Valle de Cauca navel and Indian River varieties on rough lemon stock at the Centro Nacional de Investigaciónes Agropecuariás, Palmira, during the fifth, sixth, and seventh years after planting. Palmira in the Cauca Valley is situated at 3° 31′ north latitude, 1,006 meters (3,475 feet) in elevation, and has 1,008.5 millimeters (43.2 inches) of rainfall annually (Reuther and Rios-Castaño, 1969). These yields were obtained in rootstock experiments planted on very fertile, deep, well-drained soil *without* supplemental irrigation and *without* benefit of a well-developed crop-protection technology adapted to this region.

Origin and Natural Habitat

Most of the cultivated species within the genus *Citrus* appear to be indigenous to the humid tropical regions of China, the southeast Asian countries, including the western border areas of India and Pakistan, and the islands of the Philippines and Indonesia. In this general area, primitive man undoubtedly was an active force in selectively disseminating seed of the most attractive edible species and varieties for countless centuries before the dawn of history (Stebbins, 1969). The

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fact that many of the common citrus varieties reproduce asexually from seed (see chap. 4, vol. II) and are attractive as food or condiments undoubtedly magnified man's impact on their distribution and evolution and blurred their primitive forms and areas of origin (Stebbins, 1969). Purposeful planting of seed of the most attractive and palatable citrus fruits was probably among man's earliest agricultural endeavors.

The humid tropical origin of citrus is supported also by its general mesophytic nature. It has a relatively shallow, moderately spreading rooting habit not well adapted to withstanding prolonged droughts. Its flat broad leaves and the thin, succulent bark of its twigs do not have specialized xerophytic features for greatly limiting transpiration or withstanding temperature extremes. The buds are not protected by scales or similar tissues. The absence of a regular dormancy requirement and its susceptibility to damage by freezing further support the tropical origin of citrus.

Since there are no citrus species or near relatives indigenous to the new world, it is relevent to note the conditions under which introduced citrus species spread in a natural state without cultural dependence on man. Soon after the introduction of citrus to Florida, feral groves of sour oranges, and to a lesser extent, sweet oranges, rough lemons, and West Indian limes, sprang up in certain specialized habitats. Seeds were spread purposefully or accidentally by man or animals from cultivated sources. These "wild" groves (now largely displaced) were invariably located on comparatively rich, low, moist lands found in the vicinity of lakes and rivers known locally as "hammocks." In their native state such hammocks supported good stands of tall hardwood trees and, in some instances, an admixture of sabal palms and pines. The topsoil was acid, high in organic matter and fertility, and often overlaid a calcareous subsoil. In such natural groves, varying from a few to several hundred acres in extent, citrus trees usually grew close together, forming for the most part, a dense undergrowth, under the shading canopy provided by the foliage of taller hardwoods and palms (Webber, 1943).

Apparently the principal characteristics of this hammock environment necessary for feral growth were a reasonably uniform, year-round supply of moisture in the topsoil, and a protective canopy of forest trees. Such a protective leaf canopy not only reduces the transpirational demand for soil moisture by moderation of radiation, temperature, humidity, and wind, but also affords significant protection against frost damage. Whether any other characteristics of the environment were essential requirements for feral growth is not clear. Observations by the author in various countries of Central and South America, the Carribean, and Southeast Asia indicate that the common citrus species must have substantially the environment found in tropical rain forests to successfully invade native plant communities without cultural assistance by man. The key factors for survival of seedlings appear to be a fairly well-drained fertile topsoil well supplied with moisture the year round, and freedom from extremes of temperature, humidity, wind velocity, and fluctuations in the water table. Of course, it is well known that neither native natural habitats of plants nor adopted ones are infallible indications of the best conditions for their exploitation as crop plants, but rather indicate the basic requirements for reproduction and survival. The highly specialized habitat conditions associated with feral citrus groves found in the New World do indicate, however, that the vast majority of cultivated citrus orchards now in existence in the principal production areas of the world would, if completely abandoned by man, disappear from the face of the earth without reproducing themselves, or even completing a normal life span in the harsher climatic situations. Like wheat and many other crop plants, most cultivated species and varieties of citrus probably evolved in intimate relation to man's advancement from hunter and gatherer to farmer, and thus they largely have become symbiotically linked to him.

Tree Size and Form

The commercial scion species and varieties of citrus are evergreen trees which normally reach a height of 15 to 40 or 50 feet when 25 to 35 years old. The height of mature trees depend of course, on variety, rootstock, soil conditions, pruning, and other cultural practices which influence vigor and growth habit. However, climate may also influence size.

Observations by the author and others (Bain, 1949; Mendel, 1969) indicate that in the drier climates of the far western United States, the Mediterranean Basin, and similar regions, citrus trees tend to produce somewhat smaller, thicker leaves, shorter internodes, and a more compact canopy than in the warmer, more humid

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climates such as the U. S. Gulf States, southern Brazil, and humid tropical areas. This is in general conformity with the observed effects of light intensity and moisture stress on the leaf structure of many plants (Maximov, 1935).

Energy Exchange

The studies and reviews of Brooks (1959), Gates (1962), Idso, Baker, and Gates (1960), Newman *et al.* (1967), and Chapter 10 in this volume all emphasize that the response of plants to environmental factors cannot be adequately explained by attempting to make precise, direct correlations with the conventional, widely available meteorological data. It is now clear that it is the rate of energy exchange between the plant's various tissues and organs and its environment that is an important factor which, among others, regulates the biological processes controlling growth and development. Air temperature, for example, is but one of many factors such as radiation (from various sources, both incoming and outgoing), air velocity, and relative humidity which, when integrated, determine temperatures of specific plant cells, tissues, or organs in relation to time and position. Thus, when reference is made to environmental effects in subsequent sections, a rather constant, empirical relation of tissue temperature in all parts of the aboveground portion of a plant to "air temperature" is implied. This is basically far too naive and inexact to serve as a basis for elucidating plant response to environmental conditions. Similarly, the concept of "heat summation" as a broadly applicable measure of the energy budget available to plants has serious limitations which will be discussed later. Nevertheless, the terms "air temperature" and "heat summation" will be used freely in subsequent sections because much of the literature dealing with climate and the behavior of citrus is replete with them. Hopefully, future research in the areas of environmental physiology and plant adaptation increasingly will take into account the dynamic energy exchange concept, and provide more useful measures of biologically important energy factors (Brooks, 1964).

Temperature and Rainfall Parameters

Great diversity is found among the major world citrus-growing regions, not only among mean temperature levels, but also in the amplitude of diurnal and seasonal temperature regimes. The data presented in Appendix II, table II–1 (p. 498), illustrates this diversity among the citrus regions of the United States. In the humid subtropical climate of Florida, with 2,000 to 2,400 mm (50 to 60 inches) of rainfall annually, and a virtually flat topography (maximum elevation, about 100 m), the differences in monthly mean maxima (or minima) between Homestead and Ocala, for example, seldom exceed 4° C or 5° C. In semiarid subtropical California, the comparable differences between Indio and Santa Barbara, for example, exceed 15° C in some months. Homestead and Santa Barbara are located near the ocean, while Indio and Ocala are located well inland. Homestead and Ocala are separated by 3° and 43′ of latitude (about 372 km or 231 miles) while Indio and Santa Barbara are separated by only 42′ of latitude (70 km or 42 miles). The actual separating ground distances are about 440 km (273 miles) and 322 km (200 miles), respectively. In both Homestead and Ocala, the amplitude of diurnal fluctuation is normally between 10° C and 15° C. In coastal Santa Barbara, it ranges between 12° C and 15° C, but in Indio, a very dry inland desert region, it ranges between 16° C and 20° C.

Differences in rainfall show a rather parallel situation (Appendix II, table II–2, p. 500). The rainfall at Homestead, Florida, averages 1,608 mm (63.3 in.) annually, while Ocala has 1,364 mm (53.7 inches), about 18 per cent less. However, Ocala has better distribution, with fewer months less than 64 mm (2.5 in.), about the minimum monthly precipitation required to prevent yield-depressing stress in the cooler months in Florida. Indio, California, has a total precipitation of 80 mm (3.15 in.) annually, while Santa Barbara has 448 mm (18.9 in.), a more than five-fold difference.

Commercial citrus culture is not possible without irrigation in California, Texas, and Arizona. In most of Florida, supplemental irrigation is of economic benefit in some years, but until recently, a majority of commercial orchards were not provided with facilities for irrigation. Rainfall distribution such as is found in Fairhope, Alabama, and Port Sulfur, Louisiana (Appendix II, table II–2, p. 500), normally provides adequate soil moisture the year around, with severe droughts so infrequent as to make the investment in supplemental irrigation facilities uneconomic. Both rainfall distribution and seasonal thermal regimes in Fairhope and Port Sulfur are well suited to citrus culture, but the high freeze hazard makes it marginal. At one time, there was a sizeable acreage of citrus in this Gulf of Mexico region, but now (1972) it produces very little (see chap. 2, vol. I).

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The temperature and rainfall data presented in Appendix II, table II–3 and II–4 (pp. 500–502) show that most of the citrus-growing regions around the Mediterranean Sea have rather similar subtropical climates, with hot, dry summers and cool, wet winters rather like the climates of the coastal and intermediate valleys of southern California.

The temperature and rainfall data presented in Appendix II, table II–5 and II–6 (pp. 502–504) illustrate the great diversity among climates favorable for commercial citrus culture in various parts of the world. The North Island of New Zealand represents about the coolest extreme in which citrus may be grown commercially, and Thailand is among the hottest year-round climates supporting commercial orchards of citrus.

Cañete, Perú, represents about the lowest extreme of rainfall in a commercial citrus-growing area, while that of Wakayama, Japan, is among the highest. However, some commercial citrus is grown in southeastern Thailand, for example, which has as high as 3,500 mm (138 in.) of rainfall annually, fairly well distributed throughout the year. Observations by the author in Thailand and other areas of southeast Asia and Central and South America suggest that in tropical or semi-tropical regions, at least, commercial citrus culture is marginal at 3,500 mm, if the precipitation is fairly uniformly distributed throughout the year, and the prevailing humidity remains high. Under such year-round warm, humid conditions, fungus diseases of flowers, leaves, fruit, branches, and trunks become rampant. In Southeast Asia, bacterial canker is an added problem. Also, the trees tend to accumulate a heavy burden of epiphytic and semiparasitic plants, which compete for light and favor pests and diseases (Reuther, 1969). While future research might develop improved cultural and control measures and better

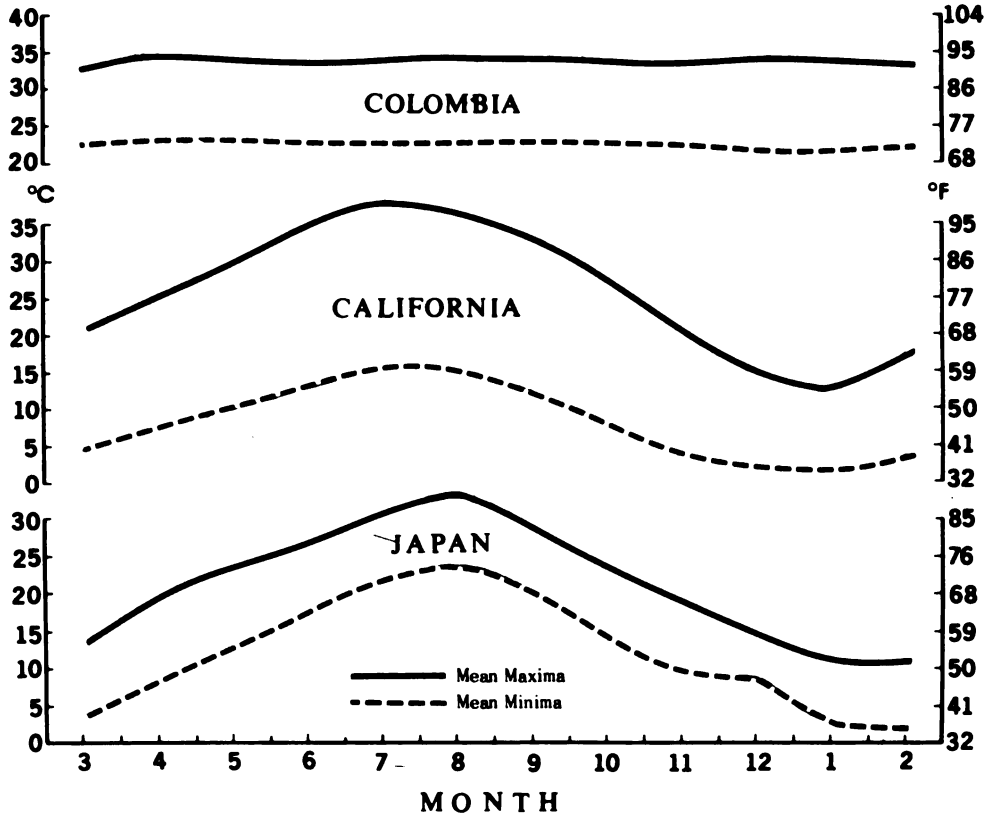

Fig. 9–2. Comparison of seasonal trends in temperature (mean monthly maxima and minima) among three very divergent climatic types utilized for citrus culture. (1) Colombia: Aracataca, Magdalena Province; latitude 10° 35′ N; elevation 33 m. (2) California: Lindsay, Tulare County; latitude 36° 11′ N; elevation 291 m. (3) Japan: Ocho, an island in the Inland Sea in Hiroshima Prefecture; latitude 34° N; elevation 30 m.

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varietal resistance, the humid tropics would probably be used best for crops which cannot be grown in drier and cooler regions.

A graphic picture of some of the extremes in temperature regimes found in citrus-growing regions of the world is presented in figure 9–2. The Aracataca, Colombia, location, about 20 km inland in the broad, flat coastal part of the Magdalena River Valley, illustrates the almost complete lack of seasonal temperature change which can occur even with monsoon-type rainfall distribution near the equator. The hottest month is April, with a mean maximum of 34.6° C (94.2° F) while March is the coolest at 32.8° C (91.0° F), a difference of only 1.8° C (3.2° F). At an elevation of 33 m and with an annual rainfall of 1,662 mm (68.1 in.), the average amplitude of diurnal change is not remarkable, but the fact that it ranges between the relatively narrow limits of 10.3° C (18.5° F) in June and 12.3° C (22.3° F) in December is not commonplace. Thus, in this lowland river valley climate of Colombia, with almost no rainfall in the December-April period, the thermal environment of a growing shoot or developing fruit remains rather constant throughout all stages of its development.

The locations plotted in figure 9–2 in California and Japan illustrate the extremes in diurnal changes found among important citrus-growing regions. The California location is in the semi-desert climate of the mountain-locked San Joaquin Valley, with a long period of sunny, hot, dry weather from May through September, and with moderate rainfall and cooler, more humid conditions during the balance of the year. Under these conditions, diurnal temperature changes range from 12° C (21.6° F) in the coolest months to 22° C (39.6° F) in the hottest. In contrast, the Japanese location is on an island at about the same latitude as the San Joaquin Valley in the Inland Sea, with rainfall fairly well distributed throughout the year. In this humid, cloudy, maritime climate, diurnal changes range between the relatively narrow limits of 4.7° C (8.5° F) and 10.8° C (19.4° F). Comparison of these two locations shows some contrast also in both the level and amplitude of seasonal changes. In California, January, the coolest month, has a mean maximum of 13.7° C (56.7° F), while July, the hottest, averages 38.1° C (100.6° F). In Japan, the comparable range is from 10.6° C (51.1° F) in January to 33.2° C (91.2° F) in August. The comparable data for mean minima are 1.5° C (34.7° F) and 15.9° C (60.6° F) for California and 2.0° C (35.6° F) and 23.9° C (75.0° F) for Japan.

Most citrus climates in various parts of the world fall somewhere in between the limits of the seasonal and diurnal ranges and amplitudes in temperature shown by the three locations illustrated in figure 9–2. How these contrasting thermal environments influence growth and development of trees and fruit will be discussed in subsequent sections.

GROUND LEVEL CLIMATIC FACTORS

Citrus specialists and others intimately familiar with the behavior of specific citrus varieties growing in different ecological situations have long recognized that there are large differences among regions in growth and yield behavior of trees and in physical and chemical characteristics of fruit produced. There are also differences in both the time lapse between bloom and market maturity and in the period that marketable fruit may be stored on the tree. Indeed, these factors determine the adaptability of a specific variety for commercial exploitation in a particular citrus-growing region. Until recently, however, few studies have been directly concerned with climatic influences on citrus. Of course, many unrelated studies have been published during the past several decades describing growth, yield, and fruit characteristics of common varieties, in relation to various cultural factors (see chaps. 4, 5, 6, 7, 8). From these data some broad influences of the climate component in the climate-soil-culture complex can be inferred, but not definitely established. Similarly, considerable data have been published over the years recording season-to-season variations, especially in fruit growth and composition in specific citrus areas, but making little contribution to knowledge isolating the causal factors (Harding, Winston, and Fisher, 1940; Harding and Fisher, 1945; Harding and Sunday, 1949; Hilgeman, Tucker, and Hales, 1959; Jahn, 1970; Long and Sunday, 1962; McCarty, Kemper, and Hield, 1965; Rasmussen *et al.*, 1966; Rygg and Getty, 1955; Tucker and Reuther, 1967).

Only in recent years have there been integrated studies with citrus aimed at disentangling climatic from edaphic and cultural factors, by investigating citrus grown in diverse ecological situations. The thrust of these studies and related evidence from other fruit crops (Reuther, 1972) is that, within the fairly broad parameters of adaptable soil and reasonably good cultural prac-

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tices, climate is probably the most important component of the climate-soil-culture complex which causes differences in growth and fruit characteristics among the commercial citrus-producing areas of the world.

From the viewpoint of plant responses, climate is a highly complex group of dynamic physical factors which influence the level and flux of available energy, the supply of metabolic raw materials (such as water, oxygen, carbon, and minerals), and the course of growth and metabolic processes. From the viewpoint of tree crop behavior, the major ground-level climatic factors that influence growth and fruiting are temperature or energy level, light, day length, rainfall, fog and dew, atmospheric humidity, and wind. From a physical viewpoint, all of these factors interact with or moderate the energy level factor. Thus, among these factors, differences in temperature, or more specifically, differences in seasonal energy regimes, are, collectively, perhaps the most important single group of elements accounting for observed differences in trees and fruit among commercial citrus-growing regions. Light for photosynthesis seldom appears to be a major limiting factor in citrus-growing areas.

In this chapter, what is known about climatic influences on citrus will be divided into two major areas: ground level climate and soil climate. This is, of course, an arbitrary division because (1) the climates of the above- and below-ground portions of a tree are interrelated and interact, and (2) the roots and top of a tree ultimately respond as a unit to an integration of external influences.

The frequency and intensity of frosts and freezes is of major importance in commercial citrus culture. The nature of cold temperature injury and methods of protection against damage by frosts and freezes are considered in detail in Chapter 10, and hence will be discussed only incidentally in this chapter.

Temperature

Before discussing the influence of temperature on growth and related plant processes covered in the following sections, it is necessary to elaborate somewhat on the special problems of delineating precise temperature effects *per se* on plant growth processes in the field or orchard. It is very difficult, especially in the orchard, to disentangle the overshadowing influence of internal moisture stress from that of other factors within the plant (such as temperature) on growth or enlargement of tissues or organs (Kramer and Kozlowski, 1960; Elfving and Kaufmann, 1972). In part, this is because the moisture stress (also called water deficit or water potential) within plant tissues is influenced in complex ways involving the interaction of temperature with a multiplicity of highly dynamic external environmental factors as well as certain ambient internal factors. Among the important environmental factors influencing water stress are radiant energy flux, temperature, relative humidity and rate of air movement, as well as temperature, moisture availability, and aeration in the soil. Some ambient internal plant factors influencing stress are stomatal resistance to transpiration, tissue temperature, and osmotic concentration of the cell sap. Still other complications tend to make precise laboratory or other controlled environment studies relating temperature to growth (Went, 1957) difficult to extend to field conditions, especially with large trees such as citrus. This is so because of the sharp temperature and other gradients that normally occur in both the above ground and soil environments in the orchard and because of the somewhat random and sometimes large day-to-day variations in amplitude and shape of diurnal radiant energy flux and air temperature cycles. Further, at least with citrus, we have little insight into the effect of day-night thermal periodicity (Hellmers, 1962, 1966) on growth processes, and its interactions with day length, root temperatures and other environmental conditions.

An additional problem is illustrated by the studies of Mooney and West (1964) and Downton and Slayter (1972). These indicate that the previous temperature conditions under which test plants are grown can induce an "acclimation" effect which can influence subsequent temperature response curves of metabolic processes such as photosynthesis at least. Future studies will undoubtedly greatly amplify understanding of the acclimation effect on growth and metabolism in plants.

The above considerations explain, at least in part, why the influence of temperature on citrus growth and related processes can only be discussed in rather gross, general terms.

Seed Germination.—The optimum temperatures for germination of seed of most plants fall between 15° C and 30° C (Langridge and McWilliam, 1967). Citrus species, perhaps because of their semitropical origin, have optimum germination of seed somewhere in the 31° C to 34° C range. Although they germinate well over a wide

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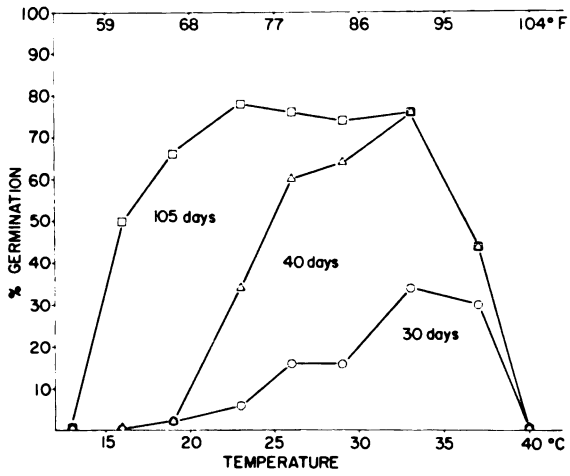

Fig. 9–3. Influence of temperature on germination (emergence) of fresh sweet orange seedlings in moist quartz sand at 30, 40, and 105 days after planting. (After Fawcett, 1929.)

range from about 20° C to about 35° C (fig. 9–3), germination is more rapid toward the higher temperature limit, while below and above these limits, it drops off very rapidly. Other available data indicate that the broad trend shown in figure 9–3 is fairly typical of common species of the genus *Citrus*. The data of Camp, Mowry, and Loucks (1933) suggest that the optimum germination temperature for grapefruit and sweet orange may be a degree or two lower than for rough lemon and sour orange. Their data also show considerable variation in germination response to temperature among batches of seed collected from different sources and at different times. Possibly some of this variability was due to disease factors which could not be adequately controlled in these early experiments.

Both the data of Barton (1943) and common experience indicate that citrus seeds have no stratification or after-ripening requirements for germination and are injured by dehydration. The studies of Elze (1949) indicate that some citrus species do germinate a little more rapidly after a brief period of stratification. Probably some preharvest factors, such as freezing exposure of fruit (Horanic and Gardner, 1958), maturity of fruit at harvest, and diseases, as well as many postharvest factors such as dehydration, storage time, and temperature, and fungicidal treatment, interact with temperature on germination, but no precise research has been done in this area. In the field seedbed, the magnitude of diurnal temperature fluctuations has a significant effect on germination of some seeds (Langridge and McWilliam, 1967), but again no data are available for citrus. This further complicates the drawing of hard and fast practical inferences from such data as are presented in figure 9–3, which were obtained with constant temperatures.

Vegetative Growth.—The early short-term laboratory studies of Girton (1927) with small controlled-temperature compartments and artificial light indicate that small seedlings of sweet and sour oranges make virtually no shoot or root elongation at a constant diurnal temperature of 12° C to 13° C (53.6° F to 55.4° F). Shoot growth rate (as measured by stem elongation or fresh weight increase) reaches a maximum somewhere between about 25° C and 31° C (77.0° F and 87.8° F) and then begins to decrease again at about 32° C to 33° C (89.6° F to 90.4° F). Root growth, on the other hand, appears to reach a maximum at about 25° C to 26° C (77° F to 78.8° F). Both root and shoot growth virtually cease at a constant diurnal temperature of 37° C to 38° C (98.6° F to 99.4° F).

Studies made for the purpose of freeing citrus clones of bud transmissable diseases by heat therapy have provided some additional data on the upper temperature limits for shoot growth. In Florida greenhouse studies, Grant (1957) obtained some shoot growth with tristeza-infected Mexican lime seedlings growing in a glass cabinet maintained constantly at temperatures ranging between 36.7° C and 40.0° C (98° F and 104° F). In Australia, Stubbs (1968) subjected various exocortis-infected lemon varieties (grafted on trifoliate orange stock growing in containers) to heat therapy by placing them in a naturally-lighted phytotron cabinet operating at a constant temperature of 38° C (100.4° F). He obtained reasonably vigorous shoot growth on such plants during periods up to about three years in the cabinet. In recent studies at Riverside, California, Calavan, Roistacher, and Nauer (1972) found that grafted nursery trees of grapefruit, sweet orange, and mandarin varieties growing in containers will produce very little shoot growth, let alone survive many days if maintained under the following conditions: a constant temperature of 38° C (100.4° F) in temperature-controlled growth cabinets set for 16 hours of artificial light and 8 hours of darkness, with constant rapid air movement. However, lemon and lime varieties did survive several months at least and produce some shoot growth under these conditions. In growth cabinets with reduced air movement set for a diurnal regime of 16 hours at 40° C (104° F) and

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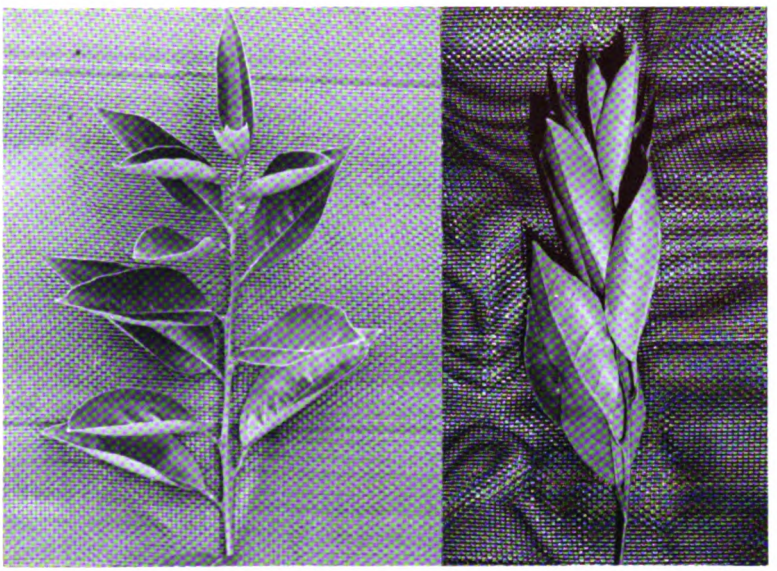

Fig. 9–4. Effect of climate on growth habit. Left: typical vigorous 2½-month-old spring-flush shoot from Olinda. Valencia tree at Riverside, California, a warm intermediate valley climate. Right: typical comparable shoot from Tustin, California, a cool coastal valley climate.

8 hours at 30° C (86° F), with corresponding 16 hours of light, 8 hours of dark, sweet oranges, mandarin, and grapefruit varieties grafted on Troyer or Rangpur stocks maintained moderate shoot growth. Seedlings of Troyer citrange and Rangpur lime produced rapid shoot growth under these conditions, while grafted varieties of lemons and Mexican lime seedlings produced an intermediate rate of shoot growth.

The growth habit of the citrus shoot appears to be influenced by the thermal environment during its development. The Valencia orange shoots shown in figure 9–4 are extreme examples selected for illustrative purposes. They show that shoots produced in a cool coastal climate in California (similar to location 17, Appendix II, table II–1) tend to have shorter internodes and leaves more closely appressed to the stem than comparable shoots produced in a warm, intermediate valley climate (location 16, Appendix II, table II–1). The author has observed this difference in growth habit in both tropical and subtropical countries with regions of great thermal diversity within short distances of each other. Such diversity may be due to the influence of proximity to the ocean or to altitude.

In subtropical climates, shoots produced during the warm summer months normally differ

Table 9–1

SEASONAL INCREASE IN CROSS-SECTIONAL AREA OF THE TRUNK AND INCIDENCE OF NEW SHOOTS IN VALENCIA ORANGE IN THREE DIVERSE CLIMATES IN THE UNITED STATES*

Period, 1961–62	Orlando, Fla.		Tempe, Ariz.		Santa Paula, Calif.	
	Trunk	Shoots	Trunk	Shoots	Trunk	Shoots
	cm^2	No.	cm^2	No.	cm^2	No.
February–March	0.0	308	0.0	244	0.3	163
April–May	5.1	0	3.8	0	0.3	23
June–July	10.6	18	7.2	1	4.8	0
August–September	14.5	28	7.0	3	9.4	0
October–November	1.9	0	3.1	1	2.7	50
December–January	1.0	0	0.3	2	0	0

Source: Adapted from Cooper *et al.* (1963).

* See Appendix II, tables II-1 and II-2 for related temperature and rainfall data. Yields (lbs per tree) were as follows: Orlando, 96; Tempe, 335, and Santa Paula, 108.

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from those produced in the cooler spring months following the dormant period. Summer flush shoots are normally longer, thicker, with larger leaves and longer internodes than spring flush shoots (Smith and Reuther, 1950; Cameron, Mueller, and Wallace, 1951; Cameron *et al.*, 1951, 1952; Mendel, 1969).

The data presented in table 9–1 illustrate other complications which tend to blur the effect of temperature *per se* on growth processes in citrus. These data illustrate that in a given subtropical climate maximum trunk growth occurs in the hottest months from June through September, while almost none occurs during the coolest months from December through March. Similarly, maximum shoot initiation occurs during the cool February–March period in all locations, with a scattering of limited "flushes" in either summer or fall, depending on the location.

This occurs despite the fact that the mean temperature during the June–September period of most rapid trunk growth in Santa Paula is around 19.5° C, while the comparable mean for Orlando is about 27.6° C (Appendix II, table II–1). Moreover, the mean temperature during the cool December–March period in Orlando, when no trunk growth occurs, is about 19.8° C, slightly above the mean during the period of maximum trunk growth in Santa Paula. These data again indicate that mean air temperature is a rather gross aspect of the thermal environment of citrus trees, and that the amplitude of seasonal and diurnal temperature cycles, among other environmental factors, probably play important roles in conditioning the growth process. They also indicate the presence of growth-conditioning internal physiological cycles in the tree, related to seasonal factors and previous thermal, cultural, and cropping history. For example, crop load may exert an overriding, influence on growth processes.

Detailed studies by Cooper *et al.* (1963), attempting to relate several tree growth measurements to various climatic parameters over a period of several years did not show any obvious correlations with the prevailing air temperatures of seven climatically-diverse citrus growing regions in the United States. The probable reasons for this already have been discussed.

The tree size data in table 9–2, with the exception of location A, were selected to represent, in the author's judgment normal or average sizes for the ages and locations listed, in commercial orchards with soils and cultural practices in the region's optimum range. Temperatures in the San Joaquin Valley (Orchard C) are similar to those of Lindsay (location 19, Appendix II, table II–1). Temperatures for Riverside (Orchard D) are presented in location 16, Appendix II, table II–1. The two Florida orchards (E and F) in table 9–2 are in locations similar climatically to Orlando (loca-

TABLE 9–2
COMPARATIVE SIZE OF ORANGE TREES IN SOME TROPICAL AND SUBTROPICAL AREAS

	Location	Variety—Rootstock	Orchard Age (years)	Number of Trees Measured	Mean Trunk Cross-Section (cm^2)	Mean Tree Canopy Dimensions	
						Height (cm)	Diameter (cm)
A.	Cali, Colombia	Valencia—rough lemon	5½	20	416	576	554
B.	Buga, Colombia	Valencia—rough lemon	5	25	203	411	493
C.	Bakersfield, California	Frost navel—Troyer	4	48	65	....	....
			7	48	147	....	....
D.	Riverside, California	Valencia—Koethen sweet	5	15	109	....	....
			12	15	248	....	....
			33	15	633	527	543
E.	Clermont, Florida	Valencia—rough lemon	5	324	101	....	....
			11	324	222	347	470
F.	Monte Verde, Florida	Valencia—rough lemon	7	96	151	....	....
			13	96	289	403	475

Sources: A and B: data supplied through the courtesy of Danilo Rios-C., Instituto Colombiano Agropecuario, Palmira, Colombia; C: data from experiments reported by Boswell *et al.* (1970); D: Citrus Experiment Station orchard, field S1. Data from files of W. P. Bitters, unpublished; E: data from experiment reported by Reuther and Smith (1952); F: data from experiment reported by Reuther *et al.* (1957).

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Fig. 9–5. Typical size of very vigorous, seven-year-old virus-free nucellar Campbell Valencia orange tree on Troyer rootstock in an experimental orchard at the University of California Lindcove Field Station (near Lindsay). (Photo taken in 1968.)

Fig. 9–6. Average size of normal, eight-year-old Valencia orange (old line) tree on rough lemon rootstock in an orchard near Clermont, Florida (Location E, table 9–2). (Photo taken in 1950.)

tion 5) summarized in Appendix II, table II–1. These data, in harmony with the studies of Cooper *et al.* (1963), suggest that there are no gross differences in the annual rate of tree growth between California and Florida, despite some substantial differences in seasonal and diurnal temperature regimes between these at two climatically diverse subtropical regions. Nevertheless, if factors such as virus and other diseases and pests, frost damage, varietal line, yield, soil moisture, and cultural factors could be held constant (virtually impossible under orchard conditions), it seems likely that average annual tree growth rate would be somewhat more rapid in the Florida climate with higher mean annual temperatures and longer growing seasons in most districts. Figures 9–5 and 9–6 illustrate trees of a size approximating those in orchards C and E in table 9–2.

The data of table 9–2 suggest that climate and related differences in annual growth of citrus trees between the tropical climate of Colombia and the subtropical climates of the United States are large enough to overshadow disease, plant, and cultural variables. Both locations in Colombia are in the Cauca Valley, with climates similar to Palmira (location 1, Appendix II, table II–5). Orchard A (see fig. 9–7) in Colombia is located on an exceptionally fertile, deep well-drained silt loam soil, receives excellent cultural care, and possibly its growth rate approaches a situation in which genetic, rather than cultural or environmental factors, are limiting. The Cauca Valley of Colombia has a daily mean maximum of near 30° C (86° F) and a mean minimum at night near 18° C (64.4° F) during all months of the year. Possibly this is near the ideal temperature regime to produce maximum annual tree growth, but not necessarily for maximum fruit production or quality. In any case, this is the most rapid of any well-documented annual citrus tree growth observed by the author in extensive travels. Similar very rapid tree growth rates in the tropics have been observed by Mendel (1969).

Flowering.—Under orchard conditions in subtropical climates appreciable flower induction of citrus species usually takes place about a month before histological evidence of flower differentiation is discernible; this usually occurs about the latter part of January in the northern hemisphere (Furr, Cooper, and Reece, 1947; Furr and Armstrong, 1956; Ayalon and Monselise, 1960). In the northern hemisphere, flower induction commonly reaches a peak in late December or early January, and normally follows six to twelve weeks of

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Fig. 9–7. Extremely vigorous five-year-old Valencia orange tree on rough lemon rootstock in an orchard near Cali, Colombia (Location A, table 9–2). (Photo taken in 1966.)

weather cool enough to induce dormancy or cessation of vegetative growth (see table 9–1). In controlled experiments, Moss (1969) found that the time required for flowering of non-induced rooted cuttings was progressively longer as temperature decreased in the 27° C/19° C, 24° C/19° C, 18° C/13° C, and 15° C/10° C series of day/night treatment regimes, but that the ultimate number of flowers produced was inversely related to temperature. Also, he showed that the cooler treatment regimes produced inflorescences with fewer leaves than did the warmer treatments. However, a period of low temperature-induced dormancy is not essential for flower induction. Dormancy induced by periods of low soil moisture supply appears about equally effective (Bain, 1949; Chandler, 1958; Cassin *et al.* 1969; Gonzalez-Sicilia, 1968; Reuther and Rios-Castaño, 1969). In tropical climates with no cool periods and ample soil moisture supply throughout the year, most citrus species produce some blooms in every month of the year, but generally tend to produce three or four major, and an equal number of lesser, bloom flushes annually (Reuther and Rios-Castaños, 1969). This behavior suggests that floral induction in citrus is not fundamentally involved with temperature *per se*, nor indeed even with dormancy, but rather with cyclic internal factors related to such factors as hormones, food supply, and crop load, among others, involving the past physiological and developmental history of particular branches. Either cool weather or drought can condition a major part of the shoots to flower at one time during the year, and this is the situation prevailing in most of the important commercial citrus regions of the world.

The data summarized in table 9–3 show the range of seasonal variations in midbloom date of Valencia oranges in some major citrus-growing areas of the United States. With the exception of Florida, season to season differences in these

Table 9–3

VARIATION IN DATES OF MIDBLOOM° OF VALENCIA ORANGE TREES IN SIX U. S. CITRUS-GROWING REGIONS DURING FIVE SEASONS

Bloom Year	Orlando, Fla.	Weslaco, Texas	Tempe, Ariz.	Indio, Calif.	Riverside, Calif.	Santa Paula, Calif.
1960	3–30	3–15	4–7	4–13	5–25	4–25
1961	3–8	.....	3–30	3–8	5–4	3–30†
1962	3–8	.....	4–7	4–7	4–27	4–27‡
1963	3–3§	3–15	4–13	4–7	5–11	5–11
1964	3–20	3–15	4–20	4–7	5–18	5–11

Source: Reuther *et al.* (1969).

° Date of 50 per cent anthesis of spring bloom estimated from distribution of petal-drop.

† Light spring bloom (February 15 through April 15) followed by two additional light blooms, one in June–July, the other in November–December.

‡ Unusually prolonged spring bloom (March through June).

§ Very sparse bloom following severe freeze injury to trees in December, 1962.

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Table 9–4
TYPICAL DISTRIBUTION OF LEMON HARVESTS IN THREE MAJOR CLIMATIC ZONES IN CALIFORNIA

Location*	Per Cent of Annual Harvest in Six Two-Months Periods					
	1–2	3–4	5–6	7–8	9–10	11–12
Thermal	....	....	....	....	73	27
Corona	45	39	10	....	....	6
Ventura	12	21	18	20	....	29

Source: Data furnished through the courtesy of W. P. Bitters; 1963 yields from similar scion-rootstock plots.

* Thermal has a very hot arid interior desert valley climate similar to Indio (location 14, Appendix II, table II–1; Corona has a warm, semi-arid intermediate valley climate similar to Riverside (location 16, Appendix II, table II–1; and Ventura has a cool coastal climate similar to Santa Barbara (location 18, Appendix II, table II–1).

regions appears to be due largely to seasonal temperature variations, since soil moisture availability is normally maintained by supplemental irrigation. Cool weather in the March–April period will tend to delay the growth and development rate of shoots and flowers, and hot weather will tend to speed it up, but quantitative relations to seasonal thermal conditions have not been elucidated. Thus, midbloom dates may vary up to six or eight weeks from season to season in a given region. In Florida, occasionally severe spring droughts may contribute to the season-to-season variation in midbloom date.

With orange, grapefruit, and mandarin varieties in most of the United States citrus regions, small blooms are common in summer or fall, setting fruit which ripens later than the main spring bloom fruit. The exceptions are the very hot, very arid citrus areas in the lower Colorado desert region of California and Arizona, which almost never produce "off-bloom." The amount of "off-bloom" seems to be influenced by internal tree factors such as the size of the spring crop as well as by environmental factors.

The blooming habit of the lemon appears to be more markedly influenced by climatic factors than that of other major citrus species. In California, for example, lemons growing in cool coastal regions with mild winters tend to bloom throughout the year, while those growing in the dry desert with hot summers and cold winters, bloom mainly in spring. The data presented in table 9–4 illustrate the large differences in patterns of lemon harvest in three diverse climates in California, due almost entirely to differences in bloom habits. The bloom habit, in turn, appears to be largely controlled by distinctive seasonal and diurnal temperature regimes in these three climatic zones. Commercial orchards in all three of these regions are irrigated as frequently as necessary to maintain favorable soil moisture throughout the year.

In studies with Washington navel orange, Lenz (1969) subjected small rooted cuttings to three day-length and two day-night-temperature regimes in naturally lit phytotron cabinets. His data indicated that flowering occurred at some of the day lengths when cuttings were grown at a temperature of 24° C day and 19° C night. When grown under a 30° C/25° C day-night regime, no flowering occurred regardless of day-length during a period of approximately eleven months. In supplementary studies, Moss (1969) used substantially the same material, methods, and facilities as Lenz (1969). He showed that rooted cuttings subjected to three widely different day-length treatments all flowered well by the end of a 17-week period of cold treatments consisting of about equal period of 15° C/5° C and 15° C/10° C day/night temperature regimes. He also found that temperatures above 30° C appeared to impair the development of flower buds. However, under orchard conditions in the tropics, flowering sufficient to set at least a moderate crop of oranges and other citrus varieties occurs in climates with day-night temperature regimes approximating 30° C/25° C. Examples occur in the lower Magdalena River Valley of Colombia (fig. 9–2) and the Chao Phya River Valley of Thailand (Bangkhen, Appendix II, table II–5). This illustrates the need for more research on climatic influences on flowering and fruit set and perhaps also the possible difficulties in relating behavior of small plants in a phytotron to large trees growing in the orchard.

Fruit Set.—As with shoot growth, it is difficult to delineate precisely temperature effects *per se* on fruit set, except at the extremes. Oranges and other citrus fruit are observed to set satisfactorily in a very wide range of thermal environments in the many diverse citrus-growing regions of the world.

In subtropical regions, a large number of blossoms are normally produced, along with a heavy flush of shoot growth in the spring each year, but a very small percentage of these actually "set" and develop into mature fruit (see chap. 2, vol. II, and Chandler, 1958). The final crop reaching maturity depends not only on the initial number of blossoms, but also on the severity of attri-

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tion of flowers and developing fruitlets during a two- to four-month period after blossoming begins. This attrition may be influenced initially by factors influencing pollination and fecundation in the ovary (see chap. 4, vol. II). Studies in Japan by Yang and Nakagawa (1970) indicate that temperatures between 15° C and 20° C are most favorable for the production of viable pollen in the anthers of satsuma orange flowers, while Iwamasa and Iwasaki (1963) and Iwamasa (1969) found that Mexican lime flowers produced in winter in an unheated greenhouse fail to set fruit because they produce largely nonviable gametes, both male and female. Factors within the tree (food reserves, mineral nutrition, hormonal balance, etc.) as well as environmental factors such as temperature, wind, humidity, soil moisture supply, and, of course, diseases and pests, all play roles in determining the fate of flowers and developing fruitlets. The rate of pollen tube growth is temperature dependent, and probably would be greatly slowed down as the temperature of the style approached 13° C, though no direct data for citrus are available. Fusion of the gametes is also probably temperature dependent (chap. 4, vol. II).

Under orchard conditions in most citrus-growing regions, no severe set problems so far have been identified associated with abnormally cool temperatures (but above freezing) prevailing during flowering. This is probably so because flowering of citrus tends to occur over several weeks' time, and a period of cool temperatures appears merely to slow down or stop flower and fruitlet development temporarily. Even if early blooms failed to set fruit because of exposure to unfavorable chilling temperatures during a critical stage of development, later flowers would tend to develop during more favorable warmer temperatures, and probably provide for an adequate set of fruits.

In a Mediterranean type climate, such as that of Riverside, California, a Valencia orange fruitlet (ovary) grows from an initial diameter of about 3 to 4 mm (0.04 to 0.08 ml volume) at anthesis to 6 to 8 mm within 30 days and to 10 to 16 mm (0.5 to 2.2 ml) within 60 days (Reuther and Nauer, 1972). By the time it reaches about 20 mm in diameter (4.2 ml), meristematic activity (cell division) is largely completed (Bain, 1958; Holtzhausen, 1969). Of course, variety and climate influence the growth rate and the duration of this early period called Stage I by Bain (1958) during which most of the fruitlet attrition occurs (see chap. 2, vol. II). However, there is a period, called

Fig. 9–8. Blackened, dehydrated persistent fruitlets typical of high temperature injury on Frost satsuma orange, Riverside, California. Injury occurred in June; photographed four months later.

"June drop" in the northern hemisphere, occurring in the May–June period in Riverside, California, when drop of Valencia fruitlets between about 10 and 25 mm in diameter (late Stage I and early Stage II) is very prominent to casual observation because the fruitlets are now large enough to be seen readily under the trees in the orchard. After the fruits attain about 25 to 30 mm (8.2 to 14.1 ml volume) in diameter, little further drop normally occurs until fruits mature.

Attrition of fruitlets during the drop period is conditioned by both internal and environmental factors. The most common adverse environmental factor is lack of adequate soil moisture, but high temperatures may also seriously reduce set. Studies by Jones and Cree (1965) indicated that very high temperatures occurring during the May–June period are correlated with poor set. Below average yields tend to occur with the "Washington" navel variety in Riverside, California if a maximum temperature above about 40° C (104° F) occurs on one or more days during the May–June period. If considerably higher maximum temperatures occur, fruitlets dry out and turn black, abscission is inhibited, and the fruitlets may persist on the tree for several months, and both fruitlets and stems may be killed (fig. 9–8). Considerable numbers of these blackened, mummified persistent fruitlets occasionally have been observed by the author in California, especially on navel orange trees in the San Joaquin and upper Santa Ana valleys in years of very poor

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navel crops. The precise air temperature maxima and other conditions associated with black fruitlets have not been delineated. Variations in their numbers from orchard to orchard within small areas, with presumably very similar exposure to high temperatures, suggest that soil moisture or other cultural conditions, leaf density, and possibly internal tree conditions may influence susceptibility to this type of high temperature damage.

Frost Valencia orange trees about six years old were grown in large containers under ambient conditions in a screenhouse at the Citrus Research Center in Riverside, California, until May, when fruitlets were about 8 to 10 mm in diameter. They were then divided into three groups, and subjected to different temperature treatments. Those trees placed in a greenhouse programmed for temperatures of 30° C–34° C (day) and 21° C–25° C (night) shed virtually all fruitlets within the next 30 days, but continued vigorous vegetative growth. Those placed in a greenhouse programmed for a 20° C–22° C and 11° C–13° C day-night regime and those remaining in the ambient Riverside screenhouse environment set a normal crop, but made less vigorous vegetative growth (Reuther and Nauer, 1972). Whether these results indicate a deleterious effect of high temperature *per se* or an indirect effect such as the creation of high moisture stress conditions within the plant is not certain. Soil moisture was maintained at high levels at all times in all treatments. In the temperature-controlled greenhouses, relative humidity was maintained above ambient most of the time. Hopefully, research in progress will clarify the roles temperature and preconditioning play in this response. But the above and similar results from other experiments, and indirect evidence in the literature concerning the effect of temperature on other growth processes in citrus, suggest that temperatures artificially maintained in the 30° C to 34° C range for 12 hours each day directly promote abscission of young fruitlets during Stage I of development.

Metabolic Processes.—Photosynthesis measurements with citrus suggest that although citrus thrives in hot, dry climates, assimilation of CO_2 by leaves has a low temperature optimum compared to many crop plants adapted to such conditions. Studies by Thompson *et al.* (1965) with leaves on well-watered rough lemon (*Citrus limon* Burm. f.) plants at low light intensity (300 ft-C) and high atmospheric humidity showed little influence of leaf temperature on rate of CO_2 assimilation (apparent photosynthesis) between

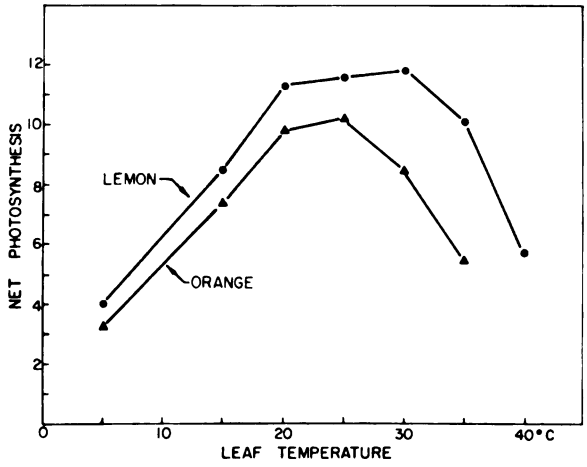

Fig. 9–9. Relation of leaf temperature to net photosynthesis (mg CO_2 $hr^{-1}dm^{-2}$) of Washington navel orange and Eureka lemon leaves attached to well-watered plants in humid air at approximately saturation light intensity about 2,500 ft-c). (Adapted from Possingham and Kriedemann, 1969.)

22° C and about 30° C, but with a slowly declining rate soon after the leaf temperature reached 32° C. The respiration studies of Possingham and Kriedemann (1969), using well watered plants, humid air, and high light intensity (2,500 ft-C; about the saturation level) indicate a maximum rate of apparent photosynthesis with Washington navel oranges at about 25° C and with Eureka lemon at about 30° C (fig. 9–9). Both of these studies show very sharp effects of factors influencing internal moisture stress of the plant not only on rate of CO_2 assimilation, but also on the apparent optimum temperature for photosynthesis.

The studies of Downton and Slayter (1972) indicate that the climatic conditions under which plants are grown can affect the temperature-photosynthesis response of plants. Hence, caution should be exercised in interpreting temperature response curves like those present in figure 9–9.

Possingham and Kriedman (1969) also showed that dark respiration of orange and lemon leaves increases almost linearly with temperature from 20° C to 35° C with a Q_{10} of about 2.

Translocation of materials in citrus, and indeed in plants generally, consists of a complex source-transport-pathway-sink system, with each element involving different (and sometimes remote) organs or tissues and diverse metabolic processes. There are very few relevant studies with citrus, and in any case, those with other plants do not lead to any generalizations useful in this type of review (Langridge and McWilliam,

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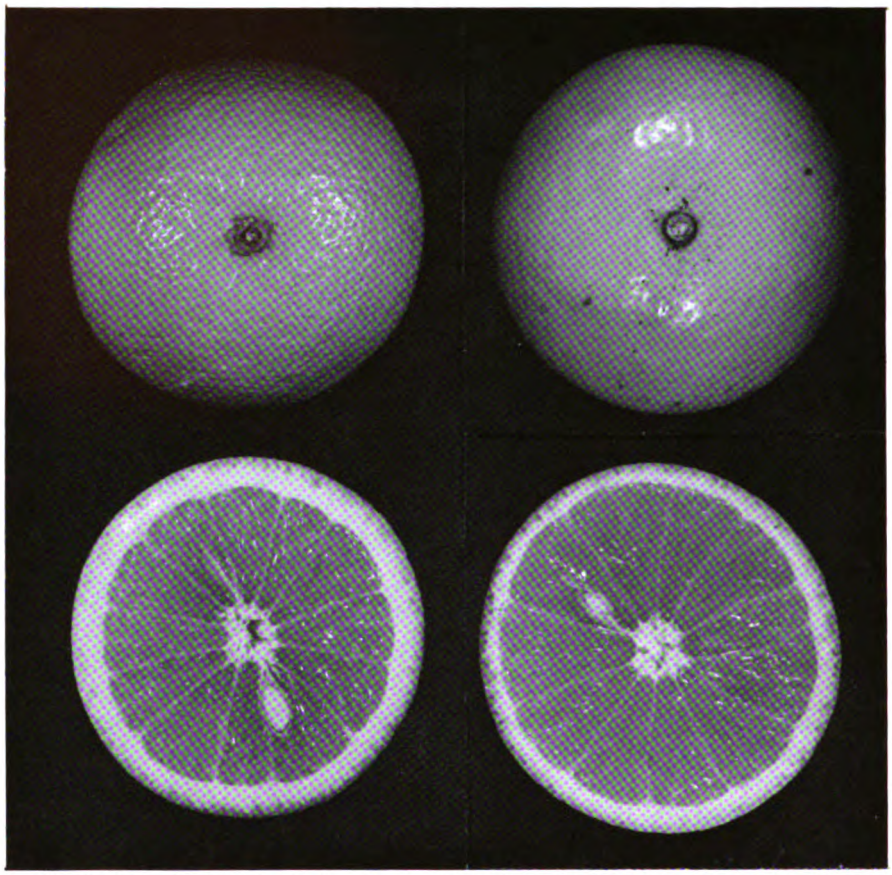

Fig. 9–10. Typical effects of climate on peel texture and thickness of Valencia oranges. Left: grown in the hot, arid Salt River Valley of Arizona. Right: grown in the hot, humid central Florida "ridge" section. Both were harvested from comparable mature trees on sour orange rootstock during the first week in March of 1965. (After Reuther *et al.*, 1969).

1969). It is useful to point out, however, that there is evidence with several plant species that significant translocation of materials takes place at temperatures below that required for active growth (Kramer and Kozlowski, 1960). Indirect evidence suggests this is so with citrus also. For example, the soluble solids content of citrus fruits may increase quite significantly even during periods when temperatures are too low for significant fruit enlargement (Reuther *et al.*, 1969; Hilgeman *et al.*, 1959; Cassin *et al.*, 1969). Wallace (1953) also found a significant nitrogen increase in the top of citrus cuttings subjected to a root temperature of 9° C. These citrus examples are in accord with Went (1953), who indicated that the temperature influence on translocation is quite distinctive from that of such other primary processes as growth, photosynthesis, and respiration, and is involved in the lower night temperature requirement for optimum growth of many plants.

Transpiration of citrus leaves and plants generally is fundamentally influenced by temperature. It is basically the loss of water to the air by evaporation, and thus depends, among other factors, on the relation between the temperature of the evaporating surfaces within the leaf, and the temperature and moisture content of the surrounding air. In citrus leaves with rather waxy, impervious cuticles, the principal evaporating surfaces are the exposed spongy mesophyll cells adjacent to the stomates (see chap. 1, vol. II, fig. 1–12). A number of studies indicate that stomates and other features of the citrus leaf structure and tree physiology enable the tree to resist or reduce moisture loss by transpiration to the atmosphere under hot, arid conditions more effectively than most crop plants grown in this type of climate (Van Bavel *et al.*, 1967).

In addition to internal and external temperature and humidity factors, other major, dynamic

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Table 9–5
INFLUENCE OF CLIMATE ON SOME MORPHOLOGICAL CHARACTERISTICS* OF FROST VALENCIA ORANGE ON TROYER ROOTSTOCK

Location California†	Weight (Gm)	Length-width Ratio	Rind Thickness (Mm)	Juice Content (Per Cent)	Date of Harvest (1970)
	118	0.96	4.8	.....	January 27
Santa Paula	124	0.96	4.8	51.6	March 11
(L)	135	0.96	5.1	53.0	April 16
	146	0.96	3.8	52.1	January 28
Tustin	165	0.97	4.1	55.3	March 11
(SC)	170	0.98	4.1	55.5	April 20
	177	1.02	4.7	49.5	January 26
Lindcove	191	1.03	5.4	52.4	March 12
(LC)	199	1.03	5.2	53.3	April 22
	187	1.03	4.4	44.6	January 29
Thermal‡	222	1.04	5.4	46.5	March 9
(T)	232	1.05	5.5	46.1	April 17

Source: Unpublished data (Reuther and Nauer, 1972).
* All values are means of 48 fruits at each harvest date.
† See figure 9–12.
‡ Light crop, abnormally large fruit.

factors influencing transpiration rate are wind velocity, soil moisture supply, soil temperature, stomatal opening, and, in some areas, atmospheric pollutants (Thompson *et al.*, 1967). Assuming all of these are held constant (under orchard conditions, they cannot be), the transpiration rate increases as temperature increases (see chap. 10; Kramer and Kozlowski, 1960).

Fruit Morphology.—All who have closely observed fruits of identical citrus varieties grown on the same rootstock under otherwise reasonably comparable cultural conditions in several distinct climatic zones have noted differences in such factors as shape, peel texture, peel thickness, and average size. The fruit in figure 9–10 show differences in peel texture and thickness typical of Valencia oranges grown in the arid climate of the Salt River Valley near Tempe, Arizona, and the humid climate of the "Ridge" section of central Florida near Orlando. During the first six to seven months after anthesis in each location monthly mean maxima (sensible air temperatures) are 2° C to 5° C higher, while during the remainder of the season they are 1° C to 3° C lower in Tempe than in Orlando. With the exception of two months, the monthly mean minima are similar in Tempe and Orlando (Appendix II, table II–1, p. 498).

From these data we may deduce that during most of Stages I (all tissues meristematic) and II (rapid cell enlargement) of fruit development (Bain, 1958), effective air temperatures (Went, 1957), and probably fruit tissue temperatures average higher during the day and lower during the night in Arizona than in Florida. During much of Stage III (maturation), tissue temperatures in Arizona average lower than in Florida throughout most of the diurnal cycle. In addition there are equally striking but often inverse relations to diurnal and seasonal differences in relative humidity. My observations and measurements, and other evidence, (Patt, Ahroni, and Benor, 1967), all indicate that peel surface texture of the mature fruit is pretty well fixed by the time Stage I is completed, but tends to roughen if held on the tree beyond normal harvest maturity. Peel thickness may be strongly influenced by temperatures during Stages II and III (Reuther *et al.*, 1969; Kurihara, 1969, 1971; Nii, Harada, and Kadowski, 1970; Reuther, 1972; Young, 1961, and tables 9–5 and 9–6).

Studies by Monselise and Turrell (1959) indicated that the smooth-textured citrus fruits characteristic of the cool, humid California coastal areas have peels with lower puncture pressure and higher moisture content than those of the coarser-textured fruits produced in the hot, arid, interior valleys (fig. 9–11). Thus, coastal fruit is more fragile in relation to certain climatic, cultural, and handling hazards.

The fruit illustrated in fig. 9–12 and the data in table 9–5 show the wide variations in both peel thickness of Frost Valencia oranges found among four major climatic zones adapted to citrus

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Table 9–6
INFLUENCE OF CLIMATE ON SOME MORPHOLOGICAL CHARACTERISTICS* OF DANCY MANDARIN ON TROYER CITRANGE ROOTSTOCK

Location,† California	Weight (Gm)	Length-width Ratio	Rind Thickness (Mm)	Juice Content (Per Cent)	Date of Harvest
	49	0.81	1.8	42.5	Dec. 9, 1969
Santa Paula	65	0.77	2.3	44.9	Jan. 27, 1970
(L)	65	0.77	2.1	39.9	March 11, 1970
	57	0.81	1.6	47.4	Dec. 5, 1969
Tustin	63	0.78	2.2	45.2	Jan. 28, 1970
(SC)	64	0.78	2.1	35.7	March 11, 1970
	99	0.85	2.6	46.8	Dec. 10, 1969
Lindcove	99	0.86	2.9	41.4	Jan. 29, 1970
(LC)	82	0.85	2.4	27.9	March 12, 1970
	102	0.88	2.6	46.2	Dec. 4, 1969
Thermal	83	0.94	2.9	33.0	Jan. 29, 1970
(T)	92	0.88	2.7	29.5	March 9, 1970

Source: Unpublished data (Reuther and Nauer, 1972).
* All values are means of measurements of 48 fruits at each harvest date.
† See figure 9–13.

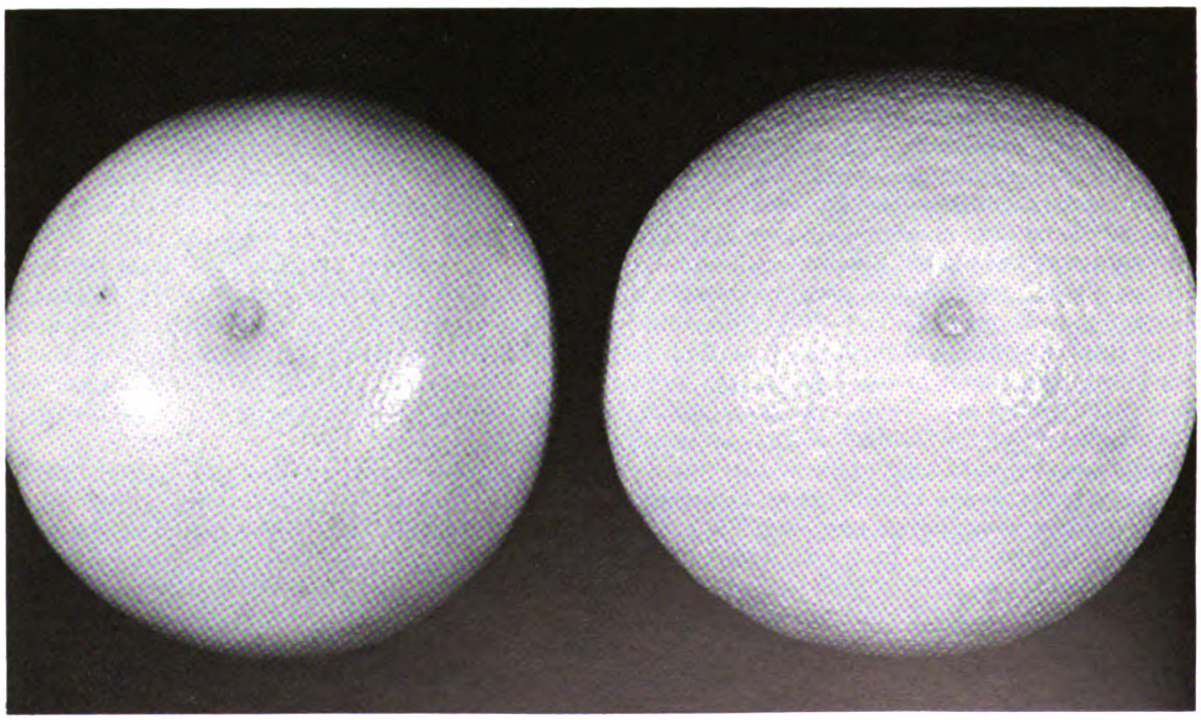

Fig. 9–11. Influence of climate on peel texture of Redblush grapefruit in California. Left: from University of California South Coast Field Station near Tustin, California with a cool, relatively humid coastal climate. Right: from University of California Lindcove Field Station near Lindsay, California, with hot, arid interior valley climate during the growing season.

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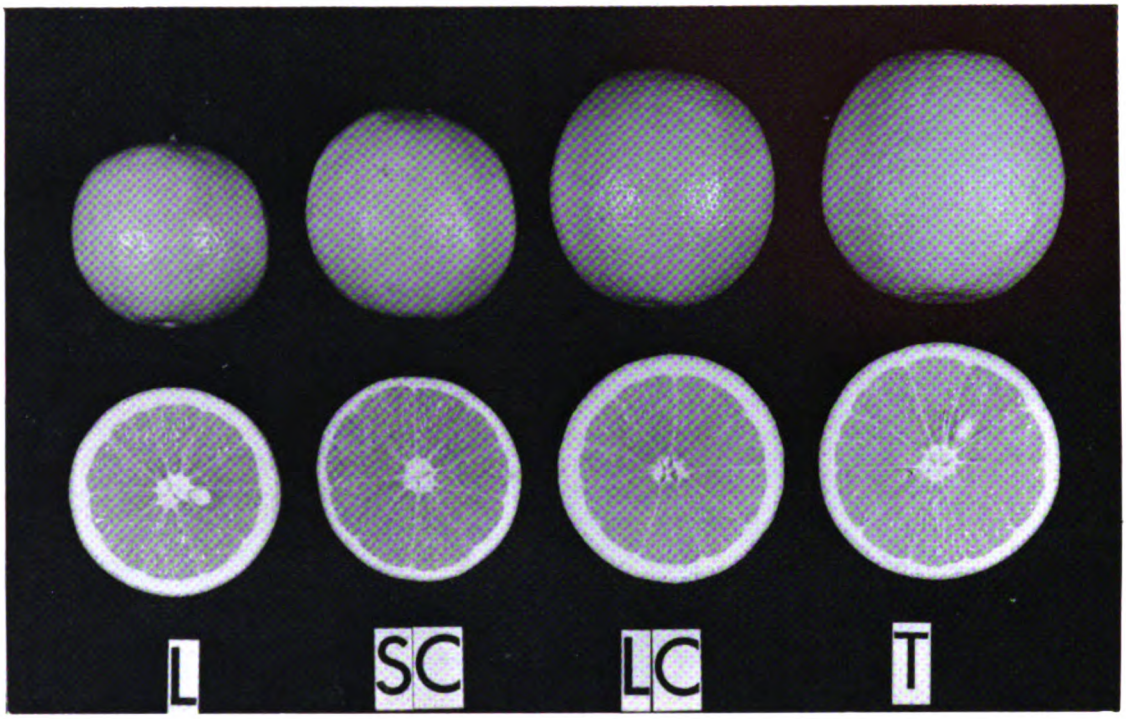

Fig. 9–12. Typical variations in peel texture and thickness of Valencia oranges (on Troyer stock) from four major citrus-growing regions of California: *L* = Limoneira experimental planting near Santa Paula, Ventura County; *SC* = South Coast Field Station near Tustin, Orange County; *LC* = Lindgrove Field Station near Lindsay, Tulare County; *T* = Commercial nursery mother block near Thermal, Coachella Valley, Riverside County. Fruits photographed were selected to show statistical means of samples harvested during the week of January 26, 1970 (see data of table 9–5).

culture in California. The length-width ratio data in table 9–5 show the rather consistent tendency of cool, humid climates to produce flatter fruits than hot, arid climates. The fruit from Limoneira were grown in a typically cool, slightly arid, coastal valley climate near Santa Paula. The University of California South Coast Field Station (near Tustin) is in a typically cool, humid, coastal plain climate. Lindcove (near Lindsay) is typical of the hot, dry San Joaquin Valley climate of inland central California. Thermal (near Indio) is typical of the very hot, very arid desert climate of the lower Colorado River Valley.

The fruit illustrated in figure 9–13 and data in table 9–6 show some typical effects of climate on shape and size of fruits of the loose-skinned mandarin group. Fruits of Dancy grown in the cooler, more humid citrus regions (Limoneira and South Coast locations) are flatter (more oblate), smaller, and usually have no necks, while those grown in the drier, hotter regions (Lindcove and Thermal) are rounder (more globose), larger and usually have necks. Similar effects of these climates on Kara mandarin were shown by Cameron and Frost (1968). With satsumas in Japan, controlled environment studies have shown in general, that cool temperatures during the pre-harvest (Stage III) period of fruit development produce flatter fruits than warm temperatures (Kurihara, 1969; Nii *et al.*, 1970). There are, of course, many other apparent effects of climate on fruit morphology such as openness of the core, degree of separation of albedo from locular walls when mature (ease of peeling), texture of flesh, and so forth, but these are less clear cut, and tend to interact strongly with season.

From figures 9–11, 9–12, and 9–13, and tables 9–5 and 9–6, it is apparent that the more humid climates with smaller seasonal and diurnal amplitudes in temperature tend to produce oranges and other type of citrus with smoother skin texture (less prominent oil glands), flatter (more oblate) shape, and less prominent necks with necked varieties than do drier climates with larger amplitudes in temperature variation. Typically, hot, humid climates during the fruit development period produce fruits with thinner peels than do hot, arid climates or cool, humid, or semi-

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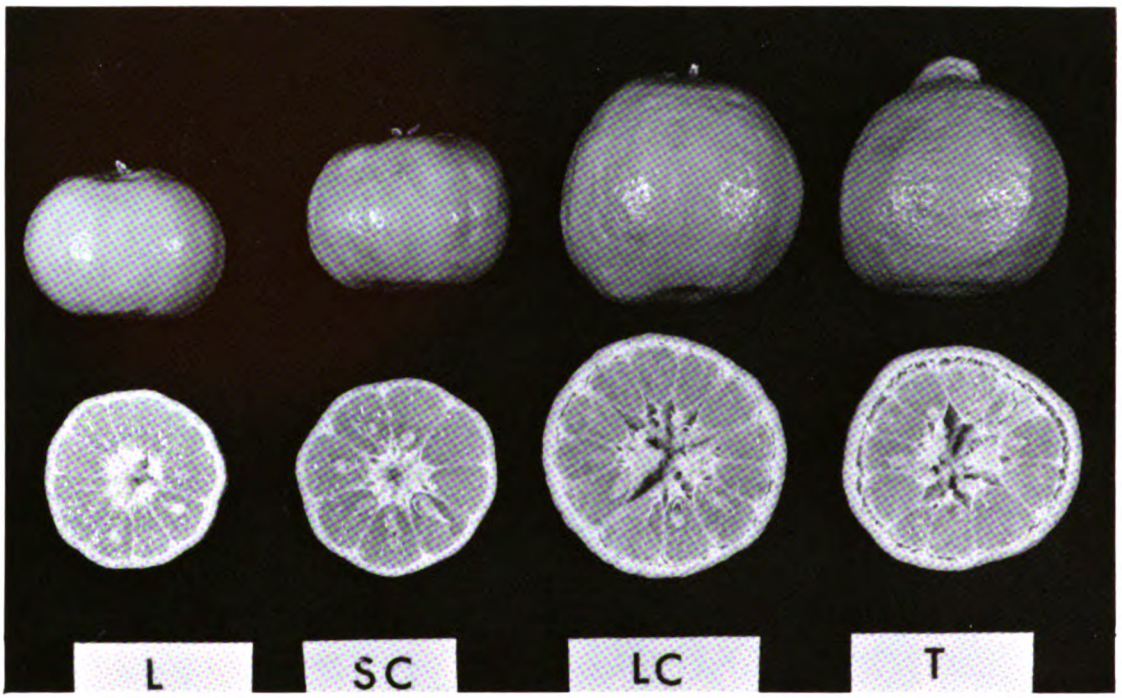

Fig. 9–13. Typical variations in size and shape of the Dancy variety (on Troyer stock) grown in four major citrus-growing regions of southern California: *L* = Limoneira experimental planting near Santa Paula, Ventura County; *SC* = South Coast Field Station near Tustin; *LC* = Lindcove Field Station near Lindsay, Tulare County; and *T* = commercial nursery mother block near Thermal, Coachella Valley, Riverside County. Fruits photographed were selected to depict statistical trends of large samples harvested during the week of January 26, 1970.

humid climates, but season-to-season variations in climate or extremes in crop load or cultural factors may overshadow this (Cooper *et al.*, 1963; Reuther *et al.*, 1969; Reuther, 1972).

The probable interrelation of temperature, humidity, and moisture stress in producing these effects will be discussed in a subsequent section. In any case, it is clear that temperature or energy level, directly and indirectly, plays an important role in influencing fruit morphology.

Fruit Growth.—Typical Valencia fruit growth curves in four diverse climates under conditions of adequate soil moisture throughout the year are presented schematically in figure 9–14. Soil moisture was supplied either by irrigation or natural rainfall, or both. The corresponding sensible air temperatures (monthly mean maxima and minima) are presented in Appendix II, tables II–1 and II–5 (pp. 498 and 502). Examination of these data indicate that sensible air temperatures and fruit growth are related only in a very broad, general way. The rate of fruit growth is slower in the Mediterranean-type, cool year-round climate of Santa Paula, California, throughout the period from anthesis to advanced senescence than it is in the seasonally warmer climates of Orlando, Florida, and Indio, California, and very much slower than in the tropical climate of Palmira, Colombia, which is uniformly warm year round. The growth curves in the three subtropical regions have a bimodal shape due to a period of slow to static growth, present during the coldest winter months, which is absent in the tropical region. In the very dry climate of Indio, California, fruit enlargement often stops completely or even shrinks during the coolest winter months when night temperatures normally drop rapidly to about 13° C or below soon after sunset. This growth pattern was noted by Hilgeman *et al.* (1959). At both Indio and Tempe, winter soil temperatures may be low enough to severely restrict water uptake by the roots (Elfving, Kaufmann, and Hall, 1972*a*, 1972*b*).

In a given location, close comparison of the slopes of various portions of the growth curve with corresponding mean maxima or minima do not reveal any consistent relationship except the tendency for growth to slow down slightly when mean minima fall below about 13° C and more sharply when they fall below about 8° C. In the

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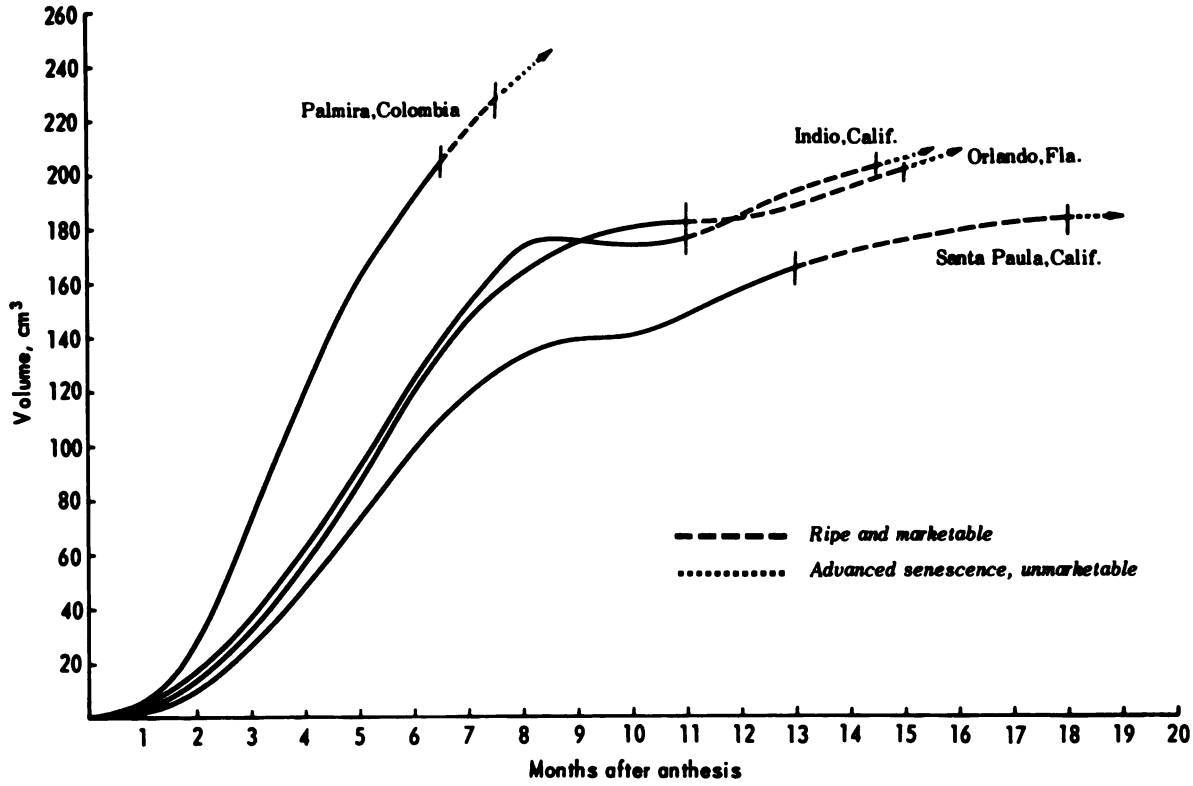

Fig. 9–14. Schematic presentation of typical Valencia orange growth curves in four widely different climatic situations with adequate soil moisture throughout the year from irrigation, natural rainfall, or both. In addition, comparative periods of immaturity, market maturity, and advanced senescence are approximated. (After Reuther *et al.*, 1969, and Reuther and Rios-Castaño, 1969.)

Table 9–7

RELATION OF MEAN SENSIBLE AIR TEMPERATURES TO RATE OF FRUIT GROWTH OF VALENCIA ORANGES DURING THE OCTOBER–NOVEMBER PERIOD, 1961, IN SEVEN CITRUS-GROWING REGIONS OF THE STATES

Location	Fruit Volumes*				Mean† Temperatures	
	On Sept 30 (Cm^3)	On Nov 30 (Cm^3)	Increase (Cm^3)	Increase (Per Cent)	Day (°C)	Night (°C)
Orlando, Florida	109	147	38	35	25	18
Clermont, Florida	112	142	30	27	23	18
Weslaco, Texas	108	145	37	34	25	18
Tempe, Arizona	90	126	36	40	19	11
Indio, California	111	147	36	32	23	13
Riverside, California	86	131	45	52	18	9
Santa Paula, California	67	101	34	51	19	10

Source: Adapted from Cooper *et al.* (1963).

* Each value is the mean for 8 fruit on each of 8 trees or of 64 observations.

† Means of hourly readings during intervals between sunrise and sunset and sunset and sunrise.

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Table 9–8
RELATION OF DEGREE-HOUR AND NET HEAT ACCUMULATIONS* TO RATE OF FRUIT GROWTH OF VALENCIA ORANGE IN FIVE DIVERSE SUBTROPICAL CLIMATES IN THE UNITED STATES DURING 1965

Location	Time from 25 Ml to 100 Ml (Days)	Net Heat Accumulation (Cals cm^{-2} min^{-1})	Degree-Hour Accumulation (Hours)
Orlando, Florida	93	26,270	51,259
Weslaco, Texas	91	28,036	63,162
Indio, California	103	37,457	75,431
Riverside, California	116	25,132	30,089
Santa Paula, California	98	19,686	18,377

Source: Adapted from Newman *et al.* (1967).
* Net heat accumulation above a mean radiant temperature of 10°C and degree-hour accumulations between 12.8°C and 35°C.

Santa Paula location, the mean minima fall below 13° C throughout the year, and in Palmira, they remain above 17.5° C throughout the year. Among locations, little obvious relation of sensible air temperature regimes to slopes of fruit curves can be discerned beyond this progressive slow deceleration beginning when the mean minima fall below about 13° C.

The data summarized in table 9–7 are typical of results obtained from a detailed examination of the relation of temperature to rate of fruit growth in a fixed time period under orchard conditions. Clearly, there is no discernible relation of air temperature conditions to fruit growth in the September–October period in the ambient environments of the orchards. Of course, the temperature data presented are the means of 60 diurnal cycles which vary greatly from day-to-day. In addition, in the seven orchards studied by Cooper *et al.* (1963), not only size and stage of fruit maturity, but also crop load varied from orchard to orchard, previous cropping history, cultural conditions, soil temperature, and moisture and climatic factors. The strong influence of crop load on rate of fruit growth is illustrated by the studies of Hilgeman *et al.* (1959 and Hilgeman, True, and Dunlap (1964). This lack of a close correlation of temperature with rate of fruit growth is in accord with earlier studies by Hilgeman *et al.*, (1959). On the other hand, Beutel (1964) found in orchard studies with recently irrigated lemon trees that fruit growth during three-day periods was directly related to daily air temperature maxima between 20° C and 33° C, but decreased at 36° C or above.

Detailed statistical studies by Newman *et al.* (1967) show that rate of fruit growth cannot be related to various methods of estimating heat budgets, such as net heat accumulation or degree-hour accumulations. The data in table 9–8 show that the most rapid growth from 25 to 100 ml (approximately Stage II of development) was made in Weslaco, and the slowest in Riverside, with a spread between the two from 91 to 116 days, a difference of about 27.5 per cent. The spread in net heat accumulations among the locations was about two-fold, and in degree-hour accumulations about four-fold, and both measures of thermal conditions apparently are completely unrelated to rate of fruit growth.

Numerous studies have shown that the fruits of many species, including citrus, typically make most of their daily net enlargement during the night or early morning (Elfving and Kaufmann, 1972; Hilgeman *et al.*, 1969; Kozlowski, 1968; Chaney and Kozlowski, 1971; Hilgeman, 1966; Tukey, 1956, 1959, 1960; Furr and Taylor, 1939; Taylor and Furr, 1937). Typical diurnal changes in volume of a young Frost Valencia orange fruit about 4.4 cm in diameter (set in the fall of 1970) is shown graphically in figure 9–15. The fruit measured was on a young tree growing under ambient conditions in a large container watered daily and held in a screenhouse admitting 60 per cent of full sunlight. The measuring technique is essentially that described by Tukey (1964). Limited data suggest that the large shrinkage in volume during the daytime on May 20 is characteristic of sunshiny days in a wide variety of climates in California (Elfving and Kaufmann, 1972). Presumably it is due to a faster rate of water loss by transpiration than of water uptake and transport to tissues. On May 21, which was variably cloudy, with a much lower heat load on the leaves, there was no appreciable shrinkage

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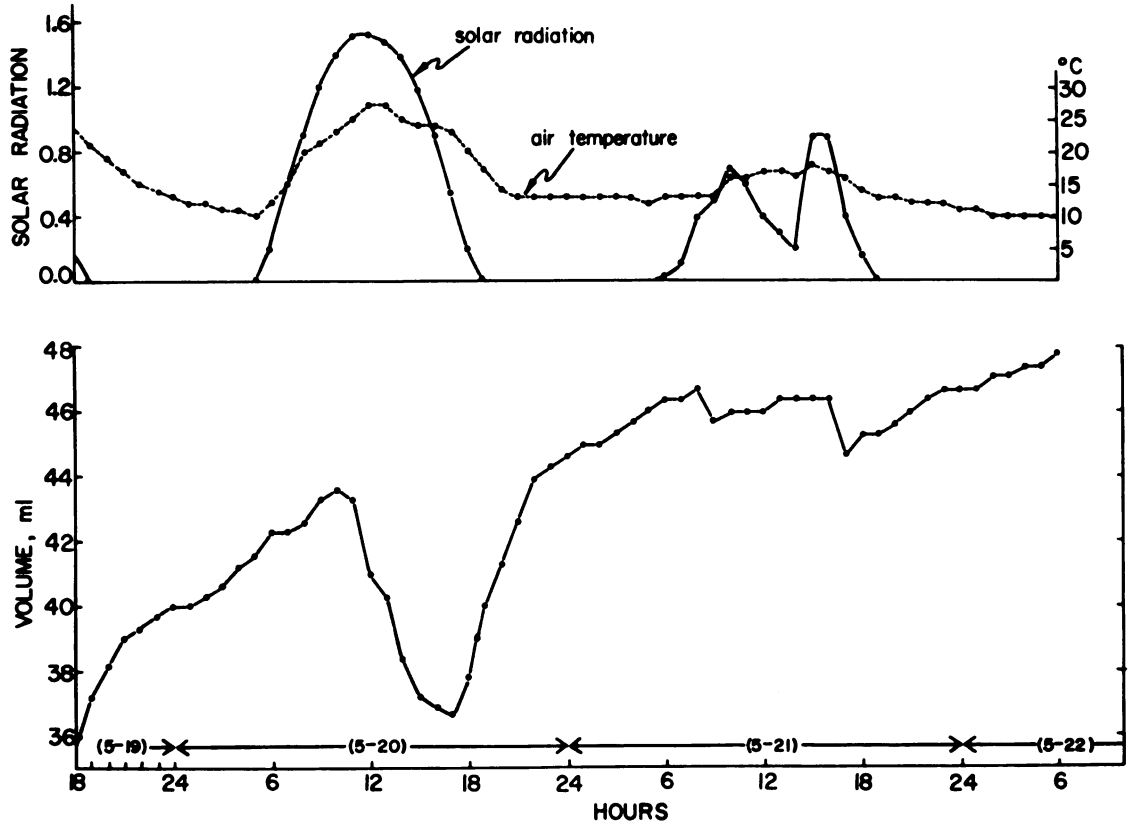

Fig. 9–15. Typical diurnal cycles of changes in volume of a young Valencia orange fruit in relation to sunshine and air temperature in Riverside, California. Solar radiation is expressed in gram calories per cm² (see Jones, Garber, and Newman, 1966), and volume was calculated from diameter, assuming the fruit to be a sphere. (From Reuther and Nauer, 1972.)

during the daytime. Other data demonstrate that on very cloudy days, citrus fruits may continue to increase in volume throughout the daylight hours (Reuther and Nauer, 1972). The net volume increase from the highest level, occurring about 09:00 hours on May 20 to the highest level at about 08:00 on May 21, probably approximates fruit growth during that period.

Detailed studies by Elfving and Kaufmann (1972) of diurnal growth curves of Valencia orange fruits under natural orchard conditions in three diverse climatic zones in California did not reveal any predictable relation between day-to-day growth rates and the associated day or night sensible air temperatures. Their data show also a progressive reduction in the amplitude of diurnal change in fruit volume as fruits approach harvest maturity. Studies by Hilgemann (1966) and Hilgeman *et al.* (1969) indicate that a large shrinkage in volume of grapefruit may occur in both Arizona and Florida in summer (Stage II) even during cool cloudy days. Obviously, more wide-ranging studies are needed to determine what climatic, soil, and plant factors determine the magnitude of diurnal shrinking and swelling of citrus fruits. Of peripheral interest are the studies of Cooper *et al.* (1963) showing that shrinking and swelling of Valencia orange tree trunks follow a cycle similar to that of fruits.

This apparent lack of a simple, clear relation between rate of fruit growth and either mean sensible temperature or net heat accumulation is probably due, under orchard conditions, to the overriding influence of the highly variable internal moisture stress factor (Elfving and Kaufmann, 1972) and to various effects of cultural factors such as mineral nutrition, crop load, and pest injury. In addition, we do not have a model for integrating the effects of the somewhat random, and sometimes large variations in day-to-

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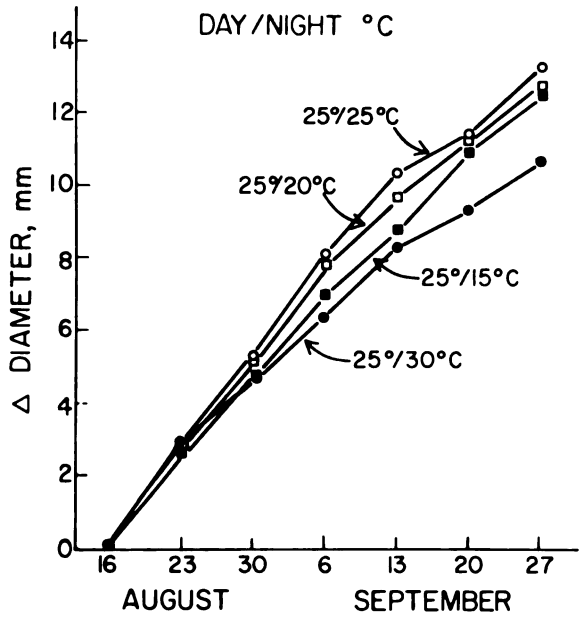

Fig. 9–16. The influence of night temperatures on the rate of increase in transverse diameter of satsuma fruits during the August-September period in controlled temperature greenhouses. Day temperatures were maintained at 25° C in all treatments. (After Nii *et al.*, 1970.)

day ambient temperature regimes. Nor do we have sufficient insight into the relative influence and possible interaction of day and night temperatures.

In recent decades, many studies have been made concerning the influence of environmental factors on growth behavior of plants through the use of sophisticated controlled-environment facilities called "phytotrons" (Went, 1957). In these, various levels of temperature, light, humidity, and air movement can be maintained within fairly narrow limits and diurnal cycles can be programmed. In recent years, a few such studies have been made with citrus. In Japan, Kurihara (1969, 1971) studied the influence of a series of programmed day-night temperatures in a "phytotron" (controlled-environment greenhouse) on growth of satsuma fruits during the fall preharvest period (Stage III) in Japan. All fruiting trees were grown in containers under identical conditions until differential treatments began early in September. In the studies reported in 1969, a graduated series of 5 day/night temperature regimes were studied, with 28° C/23° C the warmest and 13° C/8° C the coldest. At harvest in early December, fruit size was directly related to temperature, with the largest fruits in the warmest treatment about twice the weight of those in the coldest treatment. The design, however, did not permit evaluation of the relative influence of day and night temperatures. In the experiments reported in 1971, day temperatures were held constant while only night temperatures were varied. Fruit size at harvest was largest at the warmest night temperature, and smallest in the coldest, with the average weight of the largest about 40 per cent greater than the smallest. Both of these studies provide clear evidence that citrus fruits grow significantly with normal (18° C to 28° C) day temperatures when night temperatures are 8° C or lower, and even when the day/night regime is as low as 13° C/8° C. Thus fruit growth appears to have different temperature limits than does shoot growth.

Other studies with satsuma oranges in Japan by Nii *et al.* (1970), during the period August 16 to September 27 in controlled environment facilities, indicated that, within the range from 15° C to 30° C, fruit growth tends to be greatest in the 20° C to 25° C temperature range regardless of the day/night combination, but a temperature of 30° C, whether it occurs during the day or the night, depresses growth (fig. 9–16). In another series of experiments, fruit growth at four constant day and night temperatures was compared between September 27 and November 15. Here Nii found the largest increase in fruit size occurred at 20° C and the least at 30° C, with 15° C and 25° C intermediate.

Studies were made at the Citrus Research Center in Riverside, California, with Frost Valencia orange trees grown in large containers. All were grown under ambient conditions in a screenhouse until all fruits were between 2.5 to 3.5 cm in diameter. They were then divided into three groups, and subjected to the temperature environments indicated in figure 9–17. These data showed that the temperature regime prevailing in the "hot" controlled temperature greenhouse regime was less favorable for fruit growth than that of either the ambient or the "cold" greenhouse; they are typical of other fruit growth data obtained with these facilities (Reuther and Nauer, 1972). This indicates, in accordance with the findings of Nii *et al.*, (1970), that temperatures of 30° C and above appear to be not as favorable for rapid fruit growth as lower temperatures.

The controlled-environment studies reviewed above show that the rate of citrus fruit growth between about 10° C and 28° C or 30° C increases with temperature, despite the apparent

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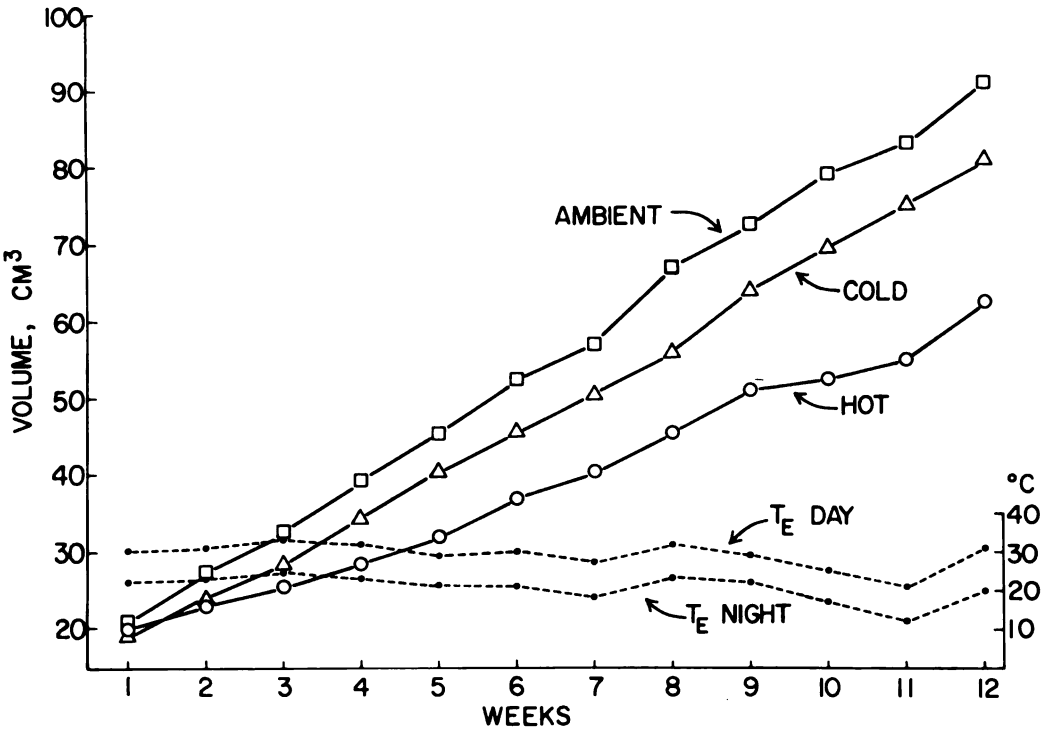

Fig. 9–17. Relations of diurnal temperature regimes to rate of growth of Valencia oranges in controlled-temperature greenhouses and ambient conditions. Each value is the mean of 16 to 40 fruit on five trees in each treatment. Differential treatments were started July 10, 1971. The cold greenhouse was programmed for a day/night regime of 20–22° C/11–13° C, and the hot for 30–34° C/20–24° C. Ambient temperatures are represented graphically, with TE (effective temperature) being the daily mean day and night temperatures estimated by the method of Went (1957).

lack of relation observed in orchard measurements. So far, however, the shape of the fruit growth rate in relation to temperature curve has not been clearly defined, but appreciable growth does appear to take place at temperatures below those favorable for vegetative growth, and may be inhibited sooner by warm temperatures. Similarly, whether the shape of this curve is influenced by variety or species, or stage of fruit development is not yet clear. No controlled environment studies have attempted to disentangle direct temperature effects *per se* from temperature effects on moisture stress within the plant. Thus, in the studies reviewed above, whether or not the reduced rate of fruit growth observed at 30° C or above is a direct temperature effect will remain an open question until further studies including parallel moisture stress measurements are made.

Studies of the diurnal shrinking and swelling regimes of citrus fruit volume during the growth reviewed above suggest that night temperatures, rather than day temperatures, largely control the growth rate, since most of the net enlargement occurs during the night and early morning hours. In controlled-environment studies with apples, Tukey (1960) made measurements indicating that fruit growth rate was influenced mainly by night temperature. However, on balance, neither the controlled environment nor the orchard studies lend any direct support to this hypothesis. Again the inference seems clear—temperature is only one of a number of major factors, both environmental and physiological, which influences the fruit growth rate.

Fruit Maturation.—The data presented schematically in figures 9–14 and 9–18 show that there is a large spread in the time required for Valencia oranges in various climatic situations to reach market maturity. In figure 9–18, a ratio of total soluble solids to acid of 9 to 1 was arbitrarily chosen as the index marking the threshold of acceptable palatability and market maturity (Harding *et al.*, 1940; Harding, 1947). The two-fold spread in the time required from anthesis to market maturity shown between Palmira (6.5 months) and Santa Paula (13 months) is probably about

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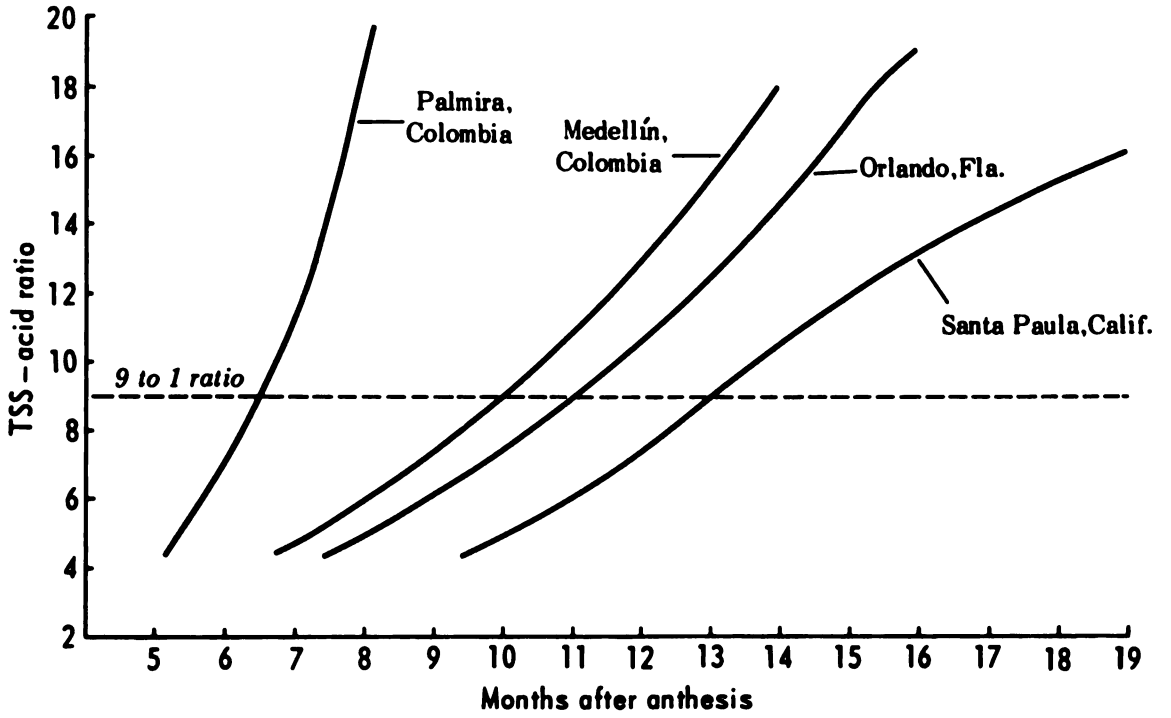

Fig. 9–18. Schematic presentation of seasonal trends in the ratio of total soluble solids to acid in juice of Valencia orange in four widely different climatic situations. The approximate dates of anthesis are: Palmira, Nov. 1; Medellín, Jan. 20; Orlando, March 15; Santa Paula, May 1. (After Reuther *et al.*, 1969; Reuther and Rios-Castaño, 1969.)

the extreme limit for climates suitable for commercial culture of oranges. Also, these two locations probably represent the approximate extremes in the length of time that the crop may be stored on the tree and remain suitable for marketing. In the tropical climate of Palmira, maturity advances very rapidly, and Valencia oranges remain suitable for marketing only about one month. In the very cool climate of Santa Paula, though, they may be harvested for market over a period of about five months. In the intermediate climates of Indio, Orlando, and Medellín, fruit normally may be stored on the tree for three to three and one-half months. If fruit are maintained on the tree into the "advanced senescence" stage shown in figure 9–19, they are unsuitable for com-

Table 9–9
COMPARISON OF MATURE AND SENESCENT FRUITS ON THE SAME TREES AT THE CITRUS RESEARCH CENTER, RIVERSIDE, CALIFORNIA

Variety	Estimated* Fruit Age (Months)	Fruit Weight (Gm)	Fruit Diameter (Cm)	Rind Thickness (Mm)	Juice Content (Per Cent)	Total Soluble Solids (Per Cent)	Anhyd. Citric Acid (Per Cent)
Catlin Sweet	13	126	6.2	2.9	64	10.7	1.1
orange	25	166	6.8	3.8	39	6.2	0.6
Berry Valencia	13	130	6.2	3.9	55	12.2	1.2
orange	25	196	7.4	4.6	26	9.5	0.7
McCarty	13	295	9.2	6.1	51	10.4	1.8
grapefruit	25	347	14.8	6.3	35	9.1	1.0

* Age from anthesis to harvest. The thirteen month-old fruit originated in the 1969 spring bloom and the twenty-five month-old fruit in the 1968 spring bloom, with April as the estimated anthesis date for both years. Harvested June 3, 1970.

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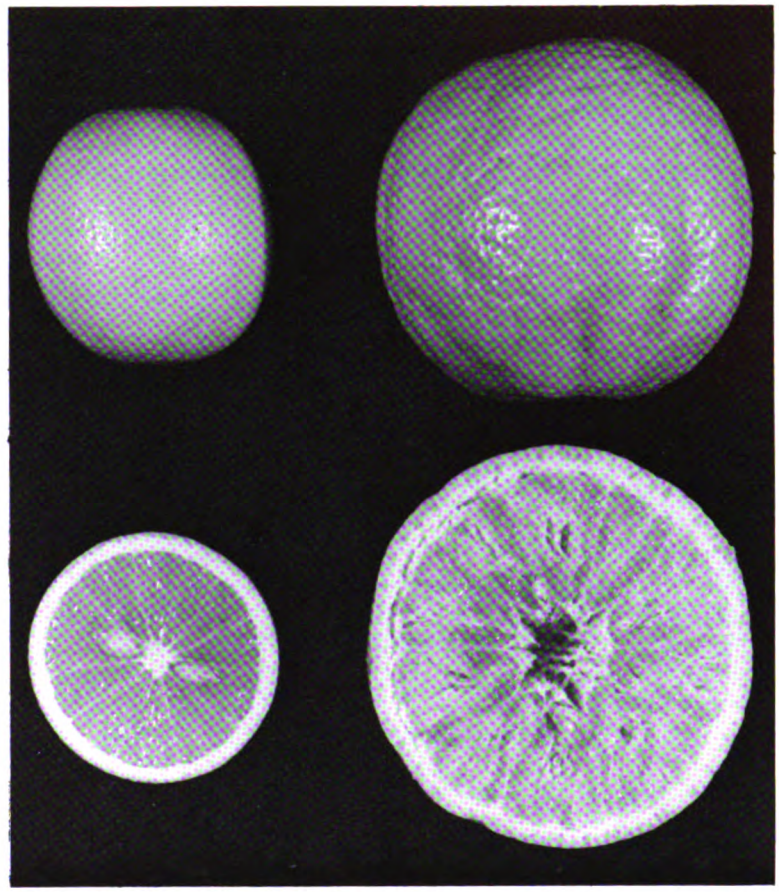

Fig. 9–19. Comparison of Valencia oranges grown on the same tree at the Citrus Research Center, Riverside, California, showing growth of fruit during advanced senescence. The fruit on the left, about 6–7 cm in diameter, originated from bloom in the spring of 1969, and is an estimated ten to eleven months from anthesis. The fruit on the right, about 10 to 11 cm in diameter, originated from bloom in the spring of 1968, and is an estimated twenty-two to twenty-three months from anthesis. (Photo taken on February 24, 1970.)

mercial marketing for a variety of reasons. Fruit growth continues, but the peel becomes excessively pebbly and thick, juice content begins to deteriorate, and acid may fall to an insipid level (about 0.5 per cent in juice or below, table 9–9). In some cases, off flavors may develop.

However, the principal reason that Valencia fruit usually cannot be maintained on the tree beyond the average limits indicated for the various climates in figure 9–14 is not that they are normally poor in palatability and appearance, but rather that they become too fragile from a shipping and marketing point of view. Spring bloom fruit harvested in August in Orlando or in December in Santa Paula are very susceptible to rind blemishes from normal packing, handling, and shipping procedures, and are very prone to decay. There are, of course, other compelling reasons for harvesting Valencia oranges as early during the period of optimum marketability as possible. Fruit stored overlong on the tree suffer progressive attrition from droppage, which may offset higher prices for late fruit in subtropical climates. Also, holding the fruit late reduces yields from the following bloom (Jones *et al.*, 1964).

As might be expected, there is considerable variation from season to season in the rate of deterioration of market quality of fruit stored on the tree. Although most varieties tend to behave more or less like Valencia as described above, some, such as navel orange and most mandarin varieties, mature in a shorter period, and deteriorate more rapidly after maturity is reached.

Unlike deciduous fruits, most citrus fruits

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continue growth after market maturity is reached. In subtropical climates, a few may remain on the tree two and one-half years or more after anthesis on trees that are not harvested. The fruits shown in figure 9–19 compare Valencia oranges on sweet orange stock ten to eleven and twenty-two to twenty-three months after anthesis. The old, senescent fruit is large, its peel is pebbly and thick with large oil glands, the albedo has separated from the locular walls, the core is hollow, the juice content of the juice vesicles is reduced, and sugar and acid in the remaining juice is also low (table 9–9). Most internal tissues seem to be in advanced stages of senescence, yet the outer peel apparently retains its meristematic character (Bain, 1958) and continues to grow. Large, coarse, dry two-year-old grapefruit are also commonly found on unharvested trees in the United States citrus regions, and some may have germinating seeds in them.

Various methods (Arnold, 1960) are used by fruit crop specialists, among others, to calculate summations of "heat units" from various types of available sensible air temperature records. Such indices are usually expressed as degree-hour or degree-day summations above a selected base temperature during a selected period of plant development. The base temperature is usually around 10° C, below which growth of most tree fruits is minimal. The objective of this technique is to secure an index of "total heat" experienced by plants or fruits during particular periods of development and relate this to some phenological factor of interest, such as length of time between the full bloom and harvest dates.

Within specific fruit-growing areas, studies with deciduous fruits and citrus have shown that seasonal variations in degree-hour or degree-day temperature summations during some early period of fruit development are inversely related to the variations in number of days between full bloom and harvest maturity, and may be used to predict the optimum harvest date in a given season (Brown, 1952, 1953; Eggert, 1960; and Jones, Embleton, and Cree, 1962). In studies with deciduous fruits, Fisher (1962) and Blanpied (1964) indicated that such relations are highly empirical, and cannot be applied except within the relatively narrow climatic parameters of season-to-season variations, within a well-defined fruit-growing area having a relatively monolithic climate. Their studies encompassed widely separated and climatically distinct apple-, pear-, peach-, and cherry-growing regions in North America. They found no consistent relation among regions between degree-day summations above 10° C during the full bloom to harvest maturity interval and the length of the interval.

Studies by Hilgeman (1941) with grapefruit in Arizona showed no correlation of heat unit summations between bloom and harvest maturity among seasons or between the Yuma and Salt River Valley districts. However, there appeared to be some correlation between date of harvest maturity and heat summations for the 60-day period preceding harvest maturity, especially between the two districts. Studies encompassing the major U. S. citrus-growing regions (Newman *et al.*, 1967) likewise showed no consistency among regions in the relation between conventional degree-hour summations and the time required from anthesis to the beginning of marketable maturity of Valencia oranges. However, the reviews of Barnard (1946), Weber (1943), Bain (1949), Mendel (1969), Cassin *et al.* (1969), and Nakagawa (1969) all indicate that there is a very broad, qualitative relationship between the degree-hour measure of heat and varietal adaptation and behavior.

Net heat accumulation data in tables 9–10 and 9–11 shed some light on the reason for the

Table 9–10
RELATION OF DEGREE-HOURS AND NET HEAT ACCUMULATIONS TO MATURATION OF VALENCIA ORANGE IN SANTA PAULA, CALIFORNIA DURING FOUR SEASONS

Crop Year and Statistical Indices	Date of Anthesis	Days to 9 to 1 Ratio	Net Heat Accumulation (Cal/cm²/min.)	Degree-Hour Accumulation (Hours)
1961–62	May 7	439	75,987	64,604
1962–62	May 3	413	71,319	55,469
1963–64	May 18	475	76,991	59,923
1964–65	May 18	431	69,567	60,258
Standard Error			1,793	1,866
Coefficient of variability (%)			5	6

Source: Adapted from Newman *et al.* (1967).

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Table 9–11
RELATION OF DEGREE-HOURS AND NET HEAT ACCUMULATIONS TO MATURATION OF VALENCIA ORANGES IN FIVE DIFFERENT SUB-TROPICAL CLIMATES DURING THE 1964–65 SEASON

Location and Statistical Indices	Date of Anthesis, 1964	Days to 9 to 1 Ratio	Net Heat Accumulation (Cal/cm²/min.)	Degree-Hour Accumulation (Hours)
Orlando, Fla.	March 27	312	72,732	120,509
Weslaco, Texas	March 16	247	69,116	142,940
Indio, Calif.	April 27	285	77,690	120,750
Riverside, Calif.	April 18	330	68,891	73,366
Santa Paula, Calif.	April 18	431	69,567	60,258
Standard error			1,673	7,015
Coefficient variability (%)			5	34

Source: Adapted from Newman *et al.* (1967).

lack of a broadly applicable fundamental "heat budget" relation between degree-hour or degree-day sensible air temperature summations and the time required to mature fruit. The data presented in table 9–10 show that at Santa Paula, California, both degree-hours (between 13° C and 35° C), and net heat (above 10° C) accumulated between anthesis and the beginning of market maturity (9 to 1 ratio) of Valencia orange is reasonably constant from season to season. The data presented in table 9–11 show that degree-hour accumulations in the interval between anthesis and the onset of market maturity vary more than two-fold among five climatically distinctive United States citrus-growing regions, but net heat accumulations are reasonably constant. This relation holds true despite the range from 247 days in Weslaco, Texas, to 431 days in Santa Paula, California, to mature Valencia oranges. Obviously, conventional air temperatures are not useful measures of energy budgets required for maturing citrus fruits, but summations based on radiant temperatures are useful approximations.

Fruit Composition.—It is not possible to formulate many meaningful generalizations on the effect of mean temperature levels during vari-

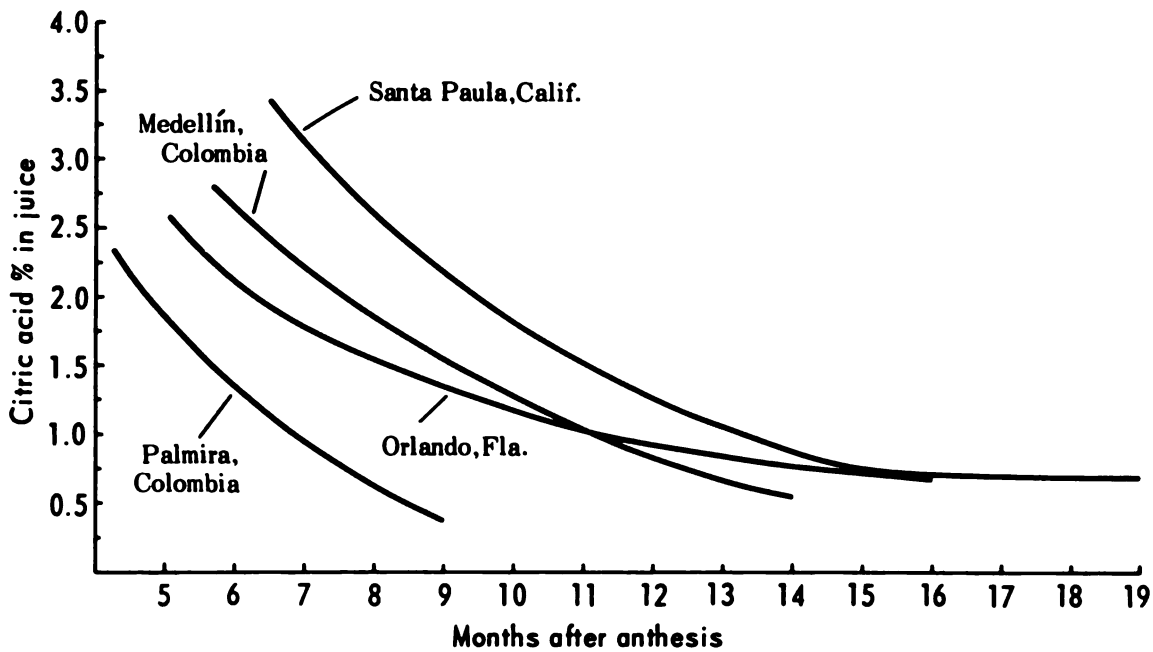

Fig. 9–20. Schematic presentation of seasonal trends in per cent acid in juice of Valencia oranges in four widely different climatic situations. (After Reuther *et al.*, 1969; Reuther and Rios-Castaño, 1969.)

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ous stages of fruit development on juice composition. There is, however, a fairly consistent broad, qualitative relationship between prevailing air temperature level and rate of decrease of acid concentration in juice, especially during the first half of Stage III of fruit development (Rasmussen *et al.* 1966; Young *et al.* 1969; Kurihara, 1969, 1971; Nii *et al.* 1970). This is illustrated schematically in figure 9–20. This is a typical family of curves obtained from orchard studies by plotting per cent acid in juice against months after anthesis in various climatic situations. The slopes of the acid curves during the first half of Stage III (1.5 to 4 months before a 9 to 1 ratio is reached) are fairly consistent functions of the prevailing temperature levels, particularly among climates that are thermally widely different. The mean monthly maxima/minima during early Stage III at Palmira are around 30° C/18° C, and Medellín around 27° C/14° C throughout the course of early Stage III. At Orlando they are around 29° C–22° C/18° C–10° C, showing a sharp drop during the fall-winter course of early Stage III. At Santa Paula, the temperature regime may be represented at 21° C–24° C/5° C–9° C, showing a rise during the winter-spring course of early Stage III in that climate. This inverse relation of temperature and acid has been found under orchard conditions with oranges, grapefruit, mandarin, and pummelos. Lemons and limes, however, appear to have as high or higher juice acid in a hot as in a cool climate (Reuther and Rios-Castaño, 1969).

The data summarized in figure 9–21 ,which shows this same inverse relation of temperature with rate of reduction of citric acid concentration in the juice of satsuma fruits, were obtained in controlled environment studies in Japan. Similarly, the data in table 9–12, which shows the strong influence of the preharvest temperature regime on acid metabolism of satsuma fruit, were obtained in controlled environments in California. These trends have also been obtained in these California facilities with Valencia oranges and Marsh grapefruit by Reuther and Nauer (1972), and with Redblush grapefruit in Texas facilities by Young *et al.* (1969).

Unlike acid, there does not appear to be any broadly applicable relation of total soluble solids content of juice to temperature. Limited observations with Valencia orange suggest that the highest solids level tends to occur in intermediate subtropical climates with at least two months

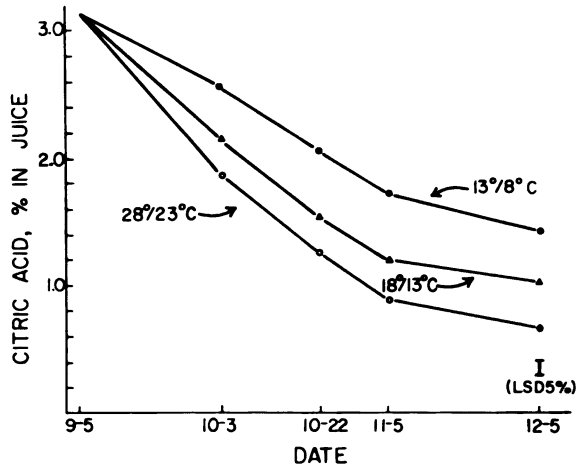

Fig. 9–21. Effect of temperature during the preharvest period (Stage III) on the rate of reduction of citric acid concentration in the juice of satsuma oranges. Comparable groups of fruiting trees growing in large containers were placed in controlled environment greenhouses on September 5, 1966 and subjected to the programmed day/night temperatures indicated. (Adapted from Kurihara, 1969.)

of weather cool enough to produce dormancy and induce a heavy spring bloom and set, and with timing of development such that some slowing of fruit growth occurs during the fall (fig. 9–18) in Stage III as the fruit is ripening. In hot tropical climates, where irrigated citrus trees tend to bloom and grow year round, the combination of high night temperature and heavy respiration losses, and competition of vegetative growth with fruit for carbohydrates apparently tends to produce lower soluble solids. However, if a moisture stress sufficient to check growth occurs during Stage III, high solids may be obtained (Reuther and Rios-Castaño, 1969; Koo and McCornack, 1965). In very cool, subtropical climates such as Santa Paula, California, Valencia oranges tend to be lower in total soluble solids at the beginning of harvest maturity than in warmer, drier, subtropical climates such as Tempe, Arizona, or Indio, California. During optimum harvest maturity, however, there is considerable season-to-season variation in the rank of total soluble solids among regions (Tucker and Reuther, 1967; Reuther *et al.*, 1969; Reuther and Rios-Castaño, 1969; Cooper *et al.*, 1963). Other orange varieties behave in much the same way as Valencia to the climatic extremes discussed above, but some, such as Washington navel and Shamouti, apparently have much narrower climatic requirements for production of high total soluble solids in juice.

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Table 9–12
EFFECT OF TEMPERATURES* DURING THE PREHARVEST PERIOD (STAGE III) ON SOME PHYSICAL AND CHEMICAL CHARACTERISTICS OF FROST SATSUMA FRUITS

Treatments	Physical Characters				Constituents of Juice		
	Length	Weight Per Fruit (Gm)	Juice Content (Per Cent)	Rind Color Index	Total Soluble Solids (Per Cent)	Anhyd. Citric Acid (Per Cent)	Ascorbic Acid (Mgm/100 ml)
Hot Greenhouse	0.80	110	43.4	8.1	9.6	0.58	21
Cool Greenhouse	0.86	76	37.8	11.2	14.2	0.93	27
Ambient Screenhouse	0.87	71	43.4	10.7	13.6	1.03	30

Source: Reuther and Nauer (1972).

* Fruiting trees on *P. trifoliata* stock were grown in large containers under ambient screenhouse conditions in Riverside, California. On October 10, 1970, comparable groups of trees were placed in controlled temperature greenhouses programmed as follows: hot, 30°–35° C day and 20°–25° C night; cool 20°–22° C day and 11°–13° C night. A control group remained in the screenhouse with ambient temperatures. The greenhouses and the screenhouse were covered with plastic screen admitting 60 per cent of ambient sunlight. Fruits for analysis were harvested January 14, 1971. The values presented are means of twenty fruits per tree from each of five trees in each treatment. Analytical procedures are essentially those described by Harding *et al.*, (1940).

In controlled-environment studies in Japan with fruiting satsuma trees in containers, Kurihara (1969) showed that a programmed day/night temperature regime of 28° C/23° C applied during the three-month preharvest period produced lower total soluble solids concentration in juice than 18° C/13° C or 13° C/18° C. Similar depressing effects of high temperatures on solids in satsuma are shown in table 9–12, and have been obtained in other controlled-environment studies with Valencia oranges in California (Reuther and Nauer, 1972). An unevaluated variable in the California controlled-environment studies is cropload. Attrition from fruit dropping or splitting greatly reduced the number of fruits per tree at harvest in the hot greenhouse as compared to the other two treatments. In later studies in Japan (Kurihara, 1971), only night temperatures were varied, and highest solids in juice at harvest were obtained with night temperatures in an intermediate range. With similar controlled-environment studies of satsuma in Japan by Nii *et al.* (1970), all possible day/night combinations of the temperature series 15° C, 20° C, 25° C, and 30° C were examined in short (October 5 to November 7) preharvest period treatments. Highest solids in juice at harvest were obtained with intermediate day/night temperature regimes. With a longer (September 27 to November 15) preharvest treatment period, and day/night temperatures held *constant*, the four temperatures ranked as follows: 15° C = 11.1 per cent; 20° C = 11.7 per cent; 25° C = 9.9 per cent, and 30° C = 8.8 per cent total soluble solids in juice.

From the controlled-environment experiments reviewed above, and orchard studies in various regions (Reuther *et al.*, 1969; Reuther and Rios-Castaño, 1969; Cooper *et al.*, 1963; Hilgeman *et al.*, 1959; Tucker and Reuther, 1967) it appears that intermediate temperatures during the preharvest period (Stage III) of orange and mandarin fruit development produce the highest total soluble solids in juice at harvest maturity. However, it is clear that more studies are needed to disentangle temperature effects from those of cropload and other factors.

The controlled-environment studies of Young *et al.* (1969) indicate that widely differing pre-harvest (Stage III) temperatures regimes have little influence on the total soluble solids concentration in the juice of Redblush grapefruit. Observations by the author in several tropical countries and limited data (Reuther and Rios-Castaño, 1969) also suggest that grapefruit and pummelo varieties, unlike most orange and mandarin varieties, develop at least as high total soluble solids concentration in juice in tropical as in subtropical climates. Also, the grapefruit field surveys of Hilgeman (1941), Harding and Fisher (1945) and Rygg and Getty (1955), made in widely different subtropical climates, tend to support the above controlled-environment studies.

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So far, little is known about the effects of varying the temperature regime during Stages I and II (see Bain, 1949) on fruit morphology, maturation, or ultimate composition. In studies at Riverside, California, during the 1970–71 season (Reuther and Nauer, 1972), three similar groups of fruiting Frost Valencia orange trees growing in large containers were placed in the differential temperature treatments described in figure 9–22 for a three-month period (July through September) during Stage II of fruit development. Later all were returned to ambient conditions in the screenhouse. When the fruits were harvested for analysis around May 1, 1971 the influence of treatment on the acid concentration in juice was similar to but less pronounced than the trend shown in table 9–12 for satsumas. But the influence of treatment on the total soluble solids in juice was the reverse of the trend shown in table 9–12. Fruits from the hot treatment were higher in total soluble solids than those from the cool treatment, and hence the former probably were more mature. Similar results were obtained from parallel experiments in the 1971–72 season. Loss of fruit because of splitting in the hot treatment was very high during the differential treatment period in both seasons, and this continued during the November–April post-treatment period in the ambient screenhouse environment, so that the final crops harvested from the trees receiving the hot treatment during either Stage II or Stage III were about 25 to 30 per cent of those from the cold or the ambient-treated trees. This latter observation on the effect of temperature on fruit splitting, a serious problem in some years wherever citrus is grown, is another example of the difficulty in relating results from controlled-environment studies to orchard conditions.

Fruit Pigments.—The frost satsuma fruits shown in figure 9–22 and the data in table 9-12 illustrate typical effects on rind color of diurnal temperature regimes during Stage III of fruit development obtained in controlled-temperature greenhouses. The visual effects shown are produced by variations in the relative concentrations of the green chlorophylls and the yellow or red carotinoids. Analytical studies with fruiting plants in controlled environments all show that cool temperatures during the six to 16 weeks preceding harvest maturity promote more rapid decomposition of the chlorophylls than warm temperatures (Young and Erickson, 1961; Erickson, 1968; Kurihara, 1969, 1971; Nii *et al.*, 1970; Young *et al.*, 1969; Meredith and Young, 1969, 1971). The above studies include orange, grapefruit, and satsuma varieties. The data of Nii *et al.* (1970) suggest that warm night temperature (25° C to 30° C) have a stronger effect than warm day temperatures in producing green fruit. The studies of Caprio (1956); and Lee, Erickson, and Chichester (1971) indicate that regreening of Valencia oranges is stimulated by warm temperatures.

The above authors also found, in general, that the concentration of carotinoids in the peel and flesh, as indicated by peel analysis, color meter readings, or visual ratings tends to be inversely related to the prevailing temperatures during the preharvest period. An exception was the indication of Meredith and Young (1969) that, unlike Valencia orange behavior, carotinoids in the peel of the Redblush grapefruit were not inversely related to preharvest temperature regimes. Early field studies by Stearns and Young (1942) also indicated that peel color development of grapefruit, unlike that in orange varieties, was unaffected by the onset of temperatures of 13° C or lower.

With satsumas, Kurihara (1971) found that at constant day temperatures, very low night temperatures (0° C–8° C) during three months before harvest maturity did not produce as high a concentration of carotinoids in peel as did slightly warmer night temperatures. Studies by Nii *et al.* (1970), with only one to one and one-half month periods of differential preharvest treatment and constant day/night temperature regimes, showed that carotinoids in peel or flesh of satsuma at harvest was greatest at 20° C, and only slightly lower at 15° C, but very appreciably lower at 5° C and 30° C. Nii *et al.* (1970) also showed that xanthophyll accounted for 80 per cent or more of total carotinoids at all temperatures and that the carotene fraction in peel was relatively greater in warmer temperatures.

In two field studies (Reuther *et al.*, 1969; Reuther and Rios-Castaño, 1969), indices of rind color development in various tropical and subtropical climates were measured. The findings all supported the general conclusion that there is a strong relation between temperature, particularly during Stage III, and peel color at harvest maturity. Cooper *et al.* (1969) recently suggested that the commonly observed relation between the onset of chilly nights in subtropical climates and the beginning of yellow or orange coloration of peel with most commercial citrus varieties is a chilling injury reaction associated with a stimu-

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Fig. 9–22. Effect of various temperature regimes from October 2 to January 14 on fruits of Frost satsuma. *H* = hot controlled temperature greenhouse programmed for 30° C–35° C/20° C–25° C day/night regime; *C* = cool greenhouse, 20° C–22° C/11° C–13° C; *A* = ambient temperatures. (See table 9–12 for additional details.)

lation of ethylene production and decomposition of chlorophyll in the peel.

Recent studies by Reuther and Nauer (1972) with Valencia oranges at Riverside, California, indicated that the temperature regime during the July–October period, when rapid fruit enlargement takes place (Stage II), markedly influences the subsequent development rate of carotinoid pigments and decomposition of chlorophyll in the rind. Trees placed in a controlled temperature greenhouse on July 12 (when fruits weighed about 20 grams) programmed for a day/night temperature regime of 20° C–22° C/11° C–13° C and returned to the ambient evironment on October 14 (when fruits weighed about 100 grams) showed "color break" of fruits much later and developed orange rind color much more slowly than fruits on comparable control trees held at ambient temperatures throughout the fruit development period. This suggests that the rinds of Valencia fruits exposed to the cool temperatures in the refrigerated greenhouse during Stage II were less mature than those exposed to the much hotter ambient Riverside climate, even though there was no visible difference in rind color or mean fruit size when differential treatment was terminated. Further, these observations suggest that rind maturity is an important factor determining its response to cool winter temperatures and subsequent development rate of carotinoid and chlorophyll and decomposition of chlorophyll pigments.

The so-called blood oranges, often originating as bud mutations from common "blond" varieties, contain the pigment anthocyanin dissolved in vacuoles, principally in cells of the juice vesicles and locular walls. The fruit illustrated in figure 9–23 show the typical difference in anthocyanin concentration in Tarocco orange in two contrasting California climates. The flesh of the fruit from the moderate inland valley climate of Riverside is very heavily pigmented, while fruit from the very hot desert valley of Indio is appreciably less pigmented. In the hot tropics, anthocyanin pigmentation of this variety probably would not be visible to the eye (Reuther and Rios-

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Fig. 9–23. Effect of temperature on athocyanin concentration in flesh of Torocco blood orange. Left: grown in moderate intermediate valley climate of Riverside, California. Right: grown in very hot desert climate of Indio, California. Photo of February 20, 1970.

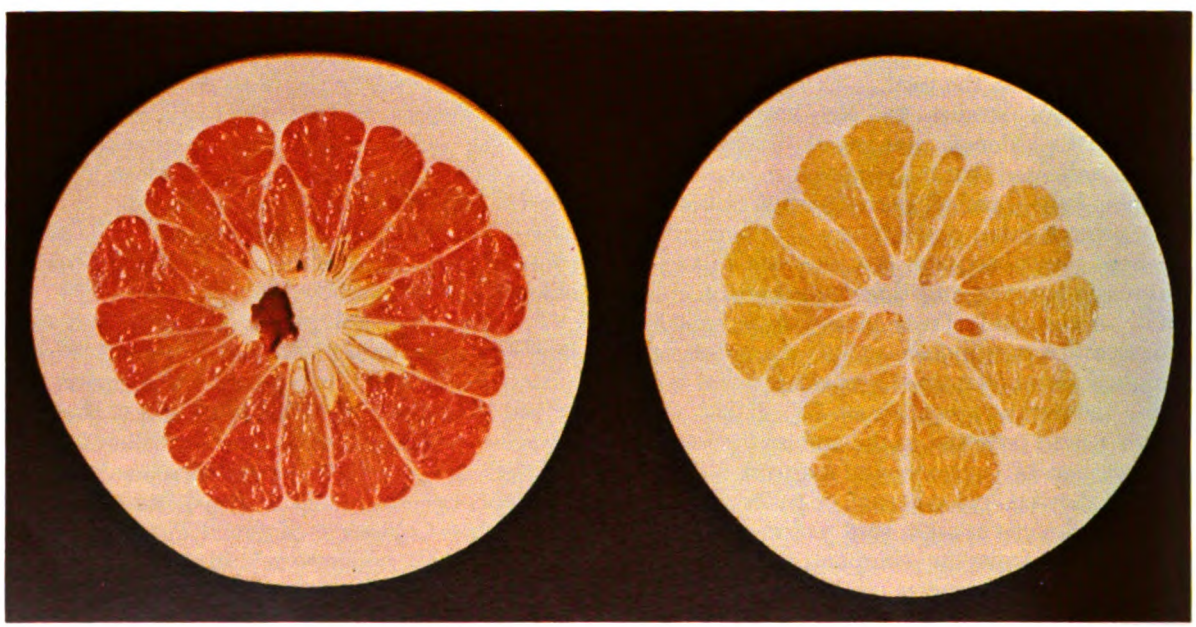

Fig. 9–24. Effect of temperature on lycopene concentration of flesh of Chandler pummelo. Left, grown in the hot climate of the San Joaquin Valley near Exeter, California. Right, grown in cool coastal valley climate near Santa Paula, California. Photo taken February 20, 1970.

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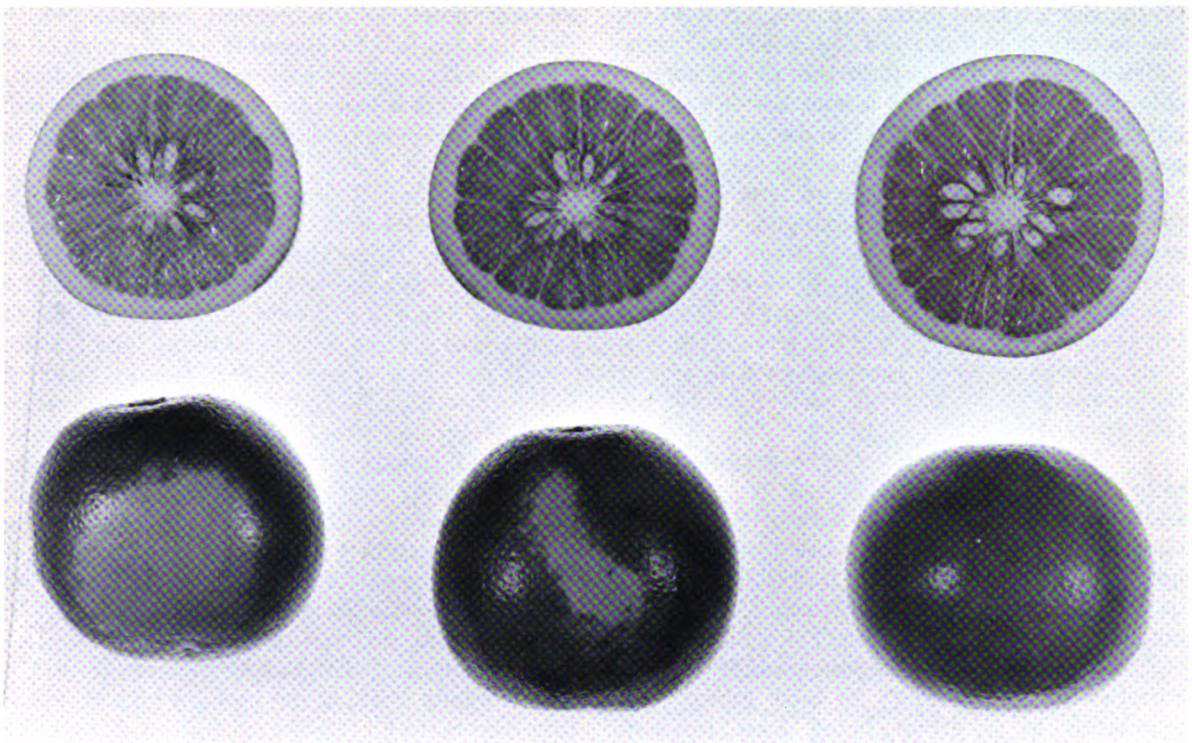

Fig. 9–25. Heat injury or sunburn of Windsor grapefruit fruits. From left to right: severe injury, moderate injury and normal. Photo taken November 15, 1971, of fruits from Citrus Research Center Orchard 7A, Riverside, California.

Castaño, 1969). Analytical studies by Meredith and Young (1969), showed that anthocyanin formation in the Ruby blood orange is inversely related to prevailing temperature levels during Stage III of fruit development.

Another pigment occurring in grapefruit and pummelo is lycopene. Redblush is a widely grown red-fleshed mutant of Marsh grapefruit which has a visible amount of lycopene in the flesh and albedo in most climates. Unlike anthocyanin, lycopene is not water soluble, but rather hydrocarbon soluble. The studies of Meredith and Young (1969), with Redblush grapefruit in controlled environments showed that lycopene concentration is directly related to temperature regime during Stage III of fruit development. Field observations in California (fig. 9–24) and in tropical areas (Reuther and Rios-Castaño, 1969) indicated that lycopene concentration in tissues at harvest maturity is high in hot climates and low in cool climates. However, very high temperatures (over 35° C) may inhibit lycopene accumulation (Meredith and Young, 1971).

Heat Injury.—A significant amount of visible heat injury to fruit, leaves, and other tissues in commercial citrus orchards occurs in regions where daily sensible air temperatures of 40° C (104° F) and above are common in the hottest months. In California and Arizona, such heat injury is a significant problem. In the Coachella, upper Santa Ana, and San Joaquin valleys of California, and in all Arizona citrus areas, (see Appendix II table II–1, Indio, Riverside, and Lindsay) daily maxima of 44° C (111° F) or above are not uncommon during the June through September period. In the Coachella Valley, absolute maxima of 49° C (120° F) and above have been recorded in some years. In Florida, sensible air temperatures rarely exceed 38° C (100° F), and visible tissue injury from heat normally is a minor problem in commercial citrus orchards.

The field observations and measurements by Ketchie and Furr (1968), Ketchie and Ballard (1968), and Ketchie (1969), made largely in the very hot, very dry Coachella Valley of California, are the basis for most of the information summarized in this section on heat injury. Typically, heat injury occurs largely on the most exposed fruits on the south side of the tree. Injured fruit usually have a visible spot on the peel (flavedo)

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on the side exposed to the sun which is light yellow to dark brown in color (fig. 9–25) and sometimes associated with a flattening of the exposed side. The yellow or brown spot has little or no chlorophyll, ruptured oil glands, and necrotic cells in varying degrees. In some instances, severely injured cells may extend from the outer peel (flavedo) into the white albedo, but severe, extensive pulp damage is rare except with some mandarin varieties (fig. 9–26). In other instances, the flavedo may appear only slightly damaged, but severe damage occurs in the underlying albedo. Lemons may show merely a flattening of the exposed side of the fruit without visible discoloration of the peel.

Although the incidence of granulation of pulp in susceptible varieties may be greater in fruits on the exposed south side of trees in hot climates, it should not be confused with heat injury. In severely heat injured fruit, juice vescicles in the pulp are actually dehydrated, but this is not the case with granulation (Erickson, 1968).

There is considerable variability among varieties in susceptibility to heat injury, with mandarins as a group being least resistant. Growth habit of the tree is an important aspect of heat resistance. In general, varieties which tend to bear their fruits within a dense protective foliage will sustain less damaged fruit. It follows that partial defoliation for whatever reason will increase the vulnerability of fruits and twigs to heat injury.

Field and laboratory measurements made in the Coachella Valley indicate that when outer peel (flavedo) temperature reaches 49° C or more, irreversable damage to cells will occur. The severity of this damage depends on the length of exposure as well as the actual tissue temperature level. Such temperatures are generally reached in the most directly exposed part of the peel when (1) the solar radiation heat load is at a maximum, (2) thermal radiation from the soil is high, (3) the air temperature is around 44° C or more, and (4) there is relatively little air movement to provide energy dissipation by convection. Pulp temperature in the center of the fruit may reach 35° C or more when conditions for peel injury occur. In some varieties, this may cause seed abortion. Detailed monitoring of the peel temperature of Valencia orange fruits in the orchard on a very hot July day in Indio, California indicated that the albedo tissue under the injured exposed portion

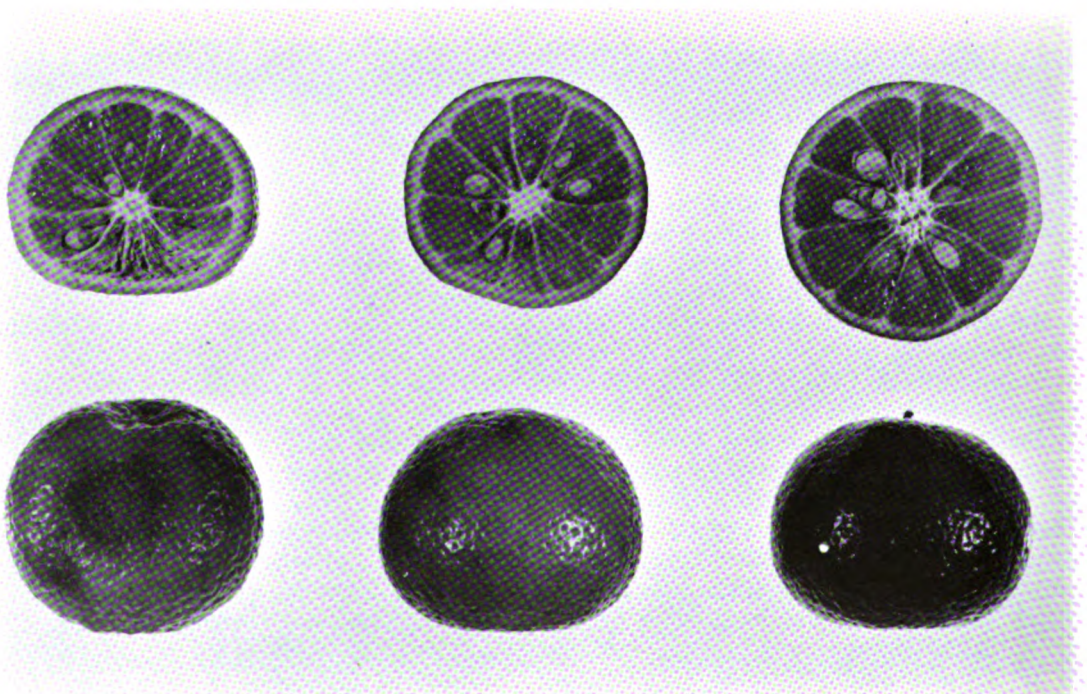

Fig. 9–26. Heat injury or sunburn of Willowleaf mandarin fruits. From left to right: severe injury, intermediate, and normal. Photo taken November 15, 1971, of fruits from Citrus Research Center Orchard 7A, Riverside, California.

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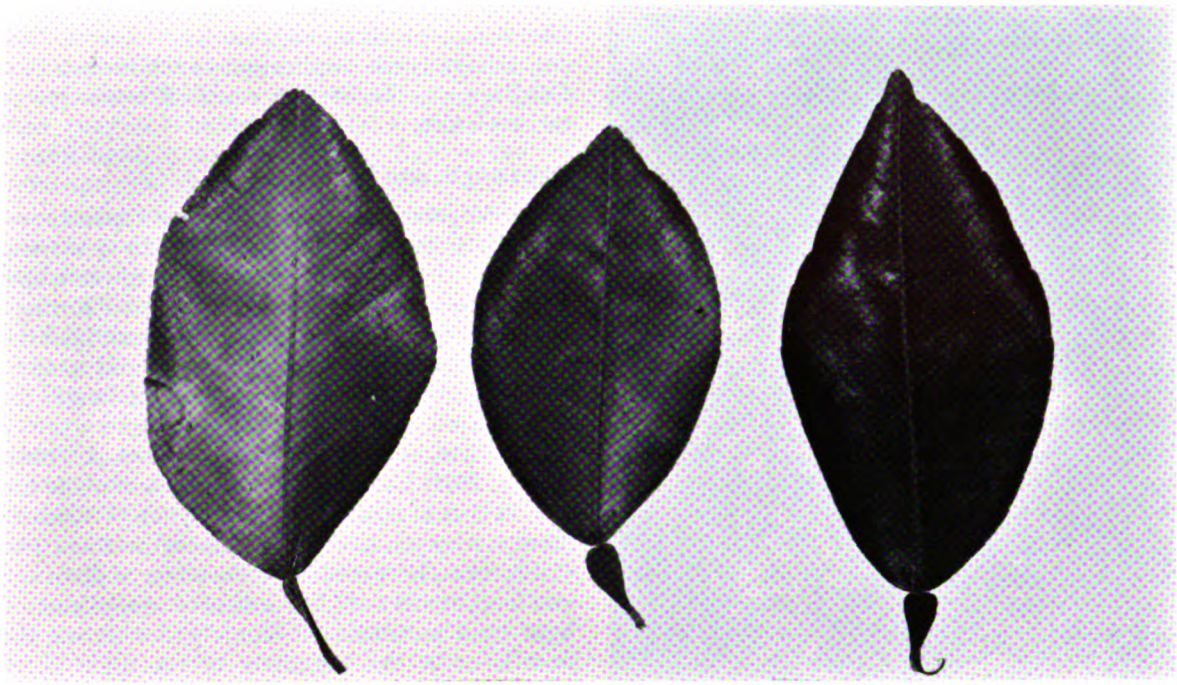

Fig. 9–27. Heat injury to grapefruit foliage. From left to right: severe yellowing with brown necrotic area, mild yellowing without necrosis and normal green leaf. Leaves from Orchard 7A, Citrus Research Center, Riverside, California. Photo taken November 15, 1971.

reached two peaks during the day (Ketchie, 1969). The highest of 48° C was reached at 11:00 A.M. when the heat load from direct solar radiation was maximal. The second peak of 44° C was reached between 2 and 4 P.M. when air temperature and thermal radiation from a warm environment reached a maximum. The first tissue temperature peak of 48° C was reached when the air temperature was 6° C lower (42° C) and the second tissue temperature peak of 44° C was reached when the air temperature was climbing from 45° C to a maximum of 48° C.

Heat injury to citrus leaves causes yellowing or browning of the blades and in some cases, necrotic lesions (fig. 9–27). The pattern of symptoms depends on severity and variety, and probably other factors. Leaf injury is associated with destruction of chlorophyll and lowered photosynthetic efficiency. In orchard studies by Ketchie (1969) near Indio, California, tissue temperature of an exposed Valencia orange leaf reached a maximum of 57° C, at which time the air temperature was 47° C. On the other hand, tissue temperatures in shaded leaves were often 5° C to 15° C cooler than air temperature. The temperature of exposed bark on a branch of the same tree reached a maximum of 50° C.

My observations in the Coachella Valley and elsewhere indicate that severely heat-damaged leaves may drop within a few days, but commonly they persist on the tree until sometime during the following fall or winter. Symptoms of heat injury to leaves on the exposed side of the tree may be observed on the day following the occurrence of damaging temperatures.

A more precise delineation of the time-temperature parameters associated with varying degrees of visible cell damage in citrus tissues must await further studies. Undoubtedly, the stage of development or maturity of the tissues and their possible adaptation by previous exposure to high temperatures, will influence susceptibility to heat damage. In addition, morphological, physiological, and other tissue-status factors may play a part. Little is known about the mechanisms involved in high temperature injury to higher plants, nor of the metabolic consequences to an organ sustaining heat injury (Langridge and McWilliam, 1967). It seems quite possible that considerable invisible and transitory metabolic derangement could take place within an organ such as a fruit or a leaf at temperatures just below the threshold of permanent, visible cell damage.

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Fig. 9–28. Stimulating influence of long days on vegetative growth of lemon seedlings under controlled environment conditions. Plants were grown on a programmed 8-hour short day (left) and a 16-hour long day (right) for 38 weeks, followed by 34 weeks on natural day lengths, but with a 3-hour light interruption in the middle of the night for the long day treatment. (Photo courtesy of Piringer *et al.*, 1961.)

So far, the only treatment that appears to afford some protection against heat injury to fruit and foliage is the application of whitewash ($CaCO_3$) sprays, but further research is needed in this area also.

Day Length and Light

Vegetative Growth.—Citrus species respond vegetatively to day length in a manner similar to that of many woody tropical plant species. Experiments with seedlings, rooted cuttings, and small budded trees grown in special facilities for programming various day length and temperature regimes show (fig. 9–28) that the longer the light period, the more total growth in a given time (Piringer, Downs, and Borthwick, 1961; Young, 1961; Lenz, 1969). Studies were made under orchard conditions with young Valencia orange trees on several rootstocks at Riverside, California. These evaluated the effect of three and one-half hours of low-intensity supplemental light from incandescant lamps either during the middle or at the beginning of the night (dark period) as compared to natural day length conditions (Nauer, 1964).[1] The treatments were compared over a period of three years. The results obtained suggested that the two supplemental light treatments probably stimulated vegetative growth slightly, but variability among the ten plants per treatment was too great to draw a firm conclusion. In any case, it is clear from these orchard studies that if there was stimulation of vegetative growth by lengthening the light period, it was much smaller than observed in the controlled environment experiments of Piringer *et al.* (1961) and Lenz (1969). Perhaps this is due to the fact that under orchard conditions at Riverside, temperatures favorable for rapid growth (see Appendix II table II–1, p. 498) occur largely during the May through October period, when day lengths (sunrise to sunset) average about 14 hours in May, reach a maximum of about 14½ hours in June, and decline gradually to about 11¼ hours in October. Twilight before sunrise and after sunset adds almost an hour to these light periods. Average day length at Riverside (34° N latitude) reaches a minimum in December of about ten hours (Wang, 1967). Thus in most of the important subtropical citrus areas of the world, during the winter months when lengthening the light period would have the best chance, under

[1] One-hundred watt bulbs and reflectors over each plant at a height adjusted to give about 20 foot candles at plant level.

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natural conditions, to stimulate vegetative growth, unfavorable temperatures predominate; during the warmer months, of course, long light periods occur naturally. The very limited data available, then, suggest that supplemental artificial low-intensity lighting to lengthen the light period or interrupt the dark period probably has little promise for influencing vegetative growth enough to have practical application in citrus orchard or field nursery practice.

There has been relatively little work done with citrus on the influence of light intensity or light quality *per se on* vegetative growth. Studies by Possingham and Kriedemann (1969) indicate that photosynthesis in orange leaves on well watered trees in humid air becomes light saturated at about 2,500 foot candles or around ¦ of full sunlight in summer in the middle of a cloudless day in most subtropical regions. In this respect, it is typical of many sun species of crop plants (Chang, 1968). Studies by Monselise (1951) indicated that light levels inside the canopy of a healthy citrus tree are typically from 0.5 to 2 per cent of that of full sunlight impinging on exposed leaves on the periphery, and that exposed leaves on the shady periphery of the tree receive a level of from 1 to 10 per cent of full sunlight. In orange trees, Greene and Gerber (1967) found that the outer one to three feet of canopy shaded the rest of the tree and that less than one per cent of the net radiation penetrated to a depth of four feet. This accounts for the "shading out" effect of the tree skirts in densely-planted crowded orchards. Thus it seems reasonable to assume that appreciably more than one fourth of a full sunlight is needed for the total leaf population of the tree to function at high efficiency for carbon assimilation. Very cloudy weather, on the other hand, probably is seldom likely to be prolonged enough in most, but probably not all, citrus-growing regions to seriously restrict vegetative growth indirectly through carbohydrate starvation.

There is almost no information on the effect of light quality on citrus growth, and indeed little enough on woody perennials generally (Borthwick, 1957; Van der Veen and Meijer, 1959). However, studies by Piringer *et al.* (1961) showed that, as in many other plants, stimulation of citrus shoot elongation by long days was dependent on a supplemental incandescent light source relatively rich in far-red in relation to red radiation. Supplemental light from a flourescent source, which emitted relatively little far red, did not produce longer internodes.

Flowering and Fruiting.—The fact that citrus species in subtropical regions in various parts of the world bloom from early spring until late fall indicates that, given an associated period of relative dormancy, flower differentation may take place either in the cool short days of mid-winter, or in the warm long days of mid-summer. Also, limited studies with mature orange trees in Florida on the effect of artificially-shortening day length by excluding daylight daily for various periods during the warmer summer and fall months tend to confirm that citrus is indeterminate with respect to photoperiod; that is, its flowering behavior is not influenced by day length (Furr *et al.*, 1947). In addition, orchard studies at Riverside (Nauer, 1964) suggested that whether or not lengthening the day or interrupting the dark period with 3½ hours of light from incandescent lamps) influenced flowering or fruit set, the effect was too small to be detected by an ordinary simple field experiment. On the other hand, Lenz's (1969) studies with rooted Washington navel cuttings in controlled environment facilities indicated that with a day/night temperature regime of 24° C/19° C, flowering occurred with both eight and twelve hours of light daily, but not with 16 hours (the treatment producing the most vegetative growth). No flowering occurred at any of the day length treatments with a 30° C/25° C temperature regime. Clearly, Lenz's results suggest that further research is needed to clarify the interrelation of dormancy, temperature, and day length to citrus flowering and fruit set.

In the Coachella Valley of California and in some other regions of the world, citrus orchards are planted in the shade of date palms or other plant species (Webber, 1943). This affords some protection from frost damage, but observations by the author in Florida and California indicate that this advantage is more than offset by production loss. In the Coachella Valley, my experience indicates that citrus production in the shade of date palms is only about one-half that obtained in comparable unshaded plantings, although fruit quality may be excellent. Thus it appears that, like coffee and some other tree fruits, citrus tolerates partial shade very well, but can only attain the high production necessary for large-scale commercial exploitation in full sun.

It is not known whether day length or light quality have any direct influence on rate of maturation or fruit quality in citrus, but indirect

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evidence suggests that they do not within the parameters found in the major citrus-growing regions.

Rainfall, Humidity, and Wind

The amount and distribution of annual rainfall and seasonal humidity regimes are very important aspects of the environmental complex which influence the adaptability of various climates to citrus culture. However, it is not feasible in this chapter to discuss the influence of rainfall or humidity on the behavior of citrus because they cannot readily be treated as discrete aspects of the environmental complex. Rainfall and relative humidity are interrelated and both affect radiation and thus moderate energy flux, which, in turn, influences tissue temperature and the vital processes going on in tissues (see energy exchange section, page 284). A major direct effect of rainfall is on the soil moisture supply, but this can be manipulated artificially through irrigation (see chap. 8).

Estimates in the subtropical United States citrus-growing regions suggest that the annual use of water by evapo-transpirational loss of water in a well-watered mature citrus orchard ranges somewhere between 762 mm (30 inches) in the cool coastal climate of Santa Barbara, California, to 1,245 mm (49 inches) in the hot semiarid climate of Weslaco in the lower Rio Grande Valley of Texas (Newman, 1968). In Tempe, Arizona, an irrigated semi-desert region, estimates indicate that a maximum monthly evapo-transpirational use of around 165 mm (6.3 inches) is reached in July, falling gradually to a minimum of about 25 mm (1 inch) in January (Van Bavel *et al.*, 1967). In tropical climates, the low transpirational use characteristic of cool temperatures and short day lengths in subtropical winters would not occur, and annual use rates even higher than found in Weslaco, Texas undoubtedly occur.

These estimates are useful only as indications of the crop's actual basic annual water use. Rainfall can never be so perfectly distributed in either time or rate, nor irrigation so efficiently applied, to maintain soil moisture between ideal limits throughout the year with annual water budgets equal to these estimates cited for the various climates. Considerably more is required to compensate for losses from runoff, deep percolation, and many other physical and plant factors influencing the uniformity of distribution and efficiency of use by the plant. Thus, the above data and discussions suggest that somewhere between 1,000 mm (39.4 inches) and 2,000 mm (78.7 inches) of rainfall would be required to maintain ideal soil moisture conditions throughout the year in mature citrus orchards. The lower figure would suffice in a cool, foggy subtropical coastal climate with rainfall distribution well correlated with seasonal temperatures and daylengths, and deep, retentive, highly permeable, well-drained and level soils. The highest figure probably would be required in a low elevation, hot tropical climate near the equator, with relatively high water demands in every month of the year. In actual fact, in few citrus areas in the world do soil and other factors provide even an approach to adequate rain-fed soil moisture for maximum production in most years. As a consequence, citrus plantings in most areas benefit from supplemental irrigation (see chap. 8).

The amount, velocity, and seasonal distribution of wind are other factors of some importance in determining the adaptability of a region to citrus culture. The major influences of these factors are of two types. The first is as an environmental component influencing energy flux. Hot winds tend to cause excessive transpirational losses, and often the death of exposed leaves through dehydration (chap. 2). Cold winds may reduce the influence of radiant energy flux either to or from tissues (chap. 10). The second effect is mechanical; tissues are bruised, and fruits become scarred. A more thorough discussion of the effects of wind, including methods of wind protection, is found in Chapter 2.

SOIL CLIMATIC FACTORS

The physical environment of the root system of a citrus tree is, in general, much more stable than that of the top. Factors such as soil temperature and moisture do not change as rapidly or have such large amplitudes diurnally and seasonally as, for example, atmosphere temperature and moisture content. An exception is the gaseous composition of the soil atmosphere, which is less stable than that of the atmosphere surrounding the top. On the other hand, the root system has a relatively stable nutrient environment. The incidence of light on the root system is almost nil, but this varies greatly both diurnally and seasonally on the top.

Unlike the top, the root system of a deep-rooted tree crop such as citrus is subject to gradients and irregularities in soil moisture, atmospheric composition, temperature, and mineral nutrients (Reuther *et al.*, 1958), although usually

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these change relatively slowly. The above-ground environmental factors, on the other hand, are relatively homogeneous throughout the aerial portion of the plant. The exception is light and other forms of incoming and outgoing radiation, which are subject to rapid changes and extreme gradients and irregularities within and about the top of the plant.

In this chapter, discussion of the soil environment will be confined to the temperature factor. Soil moisture, mineral nutrients, soil atmosphere (aeration) and related factors are discussed or touched on in Chapters 2, 4, 5, 6 and 8. In the case of soil aeration, studies dealing specifically with citrus are not extensive, but the response of citrus to soil aeration is basically similar to that of most other tree fruits, which, as a group, are relatively intolerant of imperfectly aerated soils (Boynton and Compton, 1943; Chandler, 1958; Ford, 1964, 1965; Grable, 1966; Letey *et al.*, 1967; Minnessy *et al.*, 1970; Rowe and Catlin, 1971; Camacho-Bustos, 1972).

Soil-Temperature Parameters

The temperature of the soil in the principal root zone of crop plants is influenced by both ambient and static factors. Among the most important ambient factors are daylength, amount of incoming and outgoing radiant energy, shade as a function of crop and foliage distribution and density, moisture content as a function of rainfall, irrigation and evapotranspiration, slope and aspect with respect to the sun's hourly and seasonal position, and cultural factors affecting topsoil tilth and surface mulch cover. The most important static factors are certain thermal properties such as specific heat and conductivity inherent in the organic and mineral components of the soil, and in their particle size distribution or texture (Chang, 1968; Brooks, 1959).

The great diversity among seasonal soil-temperature regimes shown in figure 9–29 is a result of the sum of the influence of major climatic and physical factors largely beyond man's practical control as well as of factors moderated by man in planting and cultivating orchards of evergreen citrus trees. Near the equator (Palmira), the amplitude of variation of monthly mean soil temperatures at a depth of 30 cm under sod is less than 2° C during the course of twelve months. Here the main variables influencing seasonal soil temperature are rainfall (see Appendix II, table II–6, p. 504) and cloudiness. Daylengths have only a minor effect since they are only about 20 minutes shorter in December than in June at 3½° N latitude. At Thermal, California, however, near 34° N latitude, daylengths in December are about 4½ hours shorter than those in June. In addition, Thermal has only about 80 mm annual rainfall, a very arid atmosphere, an extremely low incidence of cloudy weather, and very sandy soil. These are all factors which combine to produce a seasonal amplitude in variation of about 20° C between January and July in monthly mean soil temperature at 30 cm depth in an orange orchard.

The amplitudes of the seasonal soil-temperature regimes in other locations in figure 9–29 fall between these two extremes, as do those of most of the world's major citrus-growing regions. In some measure, the seasonal soil-temperature regime at a depth of 30 to 50 cm under vegetation is an integrated index of the local heat balance or net radiant energy level (Brooks, 1959), which is a major factor in determining the adaptation and growth behavior of crop plants.

The data summarized in figure 9–29 show also the great range in soil temperatures among regions adapted to extensive commercial exploitation of citrus. For example, soil temperatures at 30 cm depth in a Weslaco, Texas, orchard are from less than 2° C to more than 8° C higher than in a Ventura, California, orchard (see Appendix II, table II–1, p. 498, for the associated mean air temperatures). Throughout the nine-month growing period (March through October), soil temperatures in Weslaco are from 5° C to more than 8° C warmer than in Ventura. Similar extreme differences may be seen in comparing soil temperatures of Orlando, Florida, and Lindsay, California, except that the divergence is greatest in midwinter rather than in midsummer. In addition, these data suggest that subtropical regions suitable for large-scale commercial citrus culture have climates associated with soil temperature (monthly means at 30 cm depth) parameters somewhere in the range between about 6° C to 16° C for winter minima and between about 24° C and 36° C for summer maxima. In tropical regions like Palmira, Colombia, a climate associated with mean monthly soil temperatures at 30 cm ranging between the narrow limits of about 26° C to 28° C throughout the year, can support high yields of oranges (Torres-M. and Rios-C., 1968), although growth habits and fruit characteristics may contrast sharply with subtropical regions (Reuther and Rios-Castaño, 1969).

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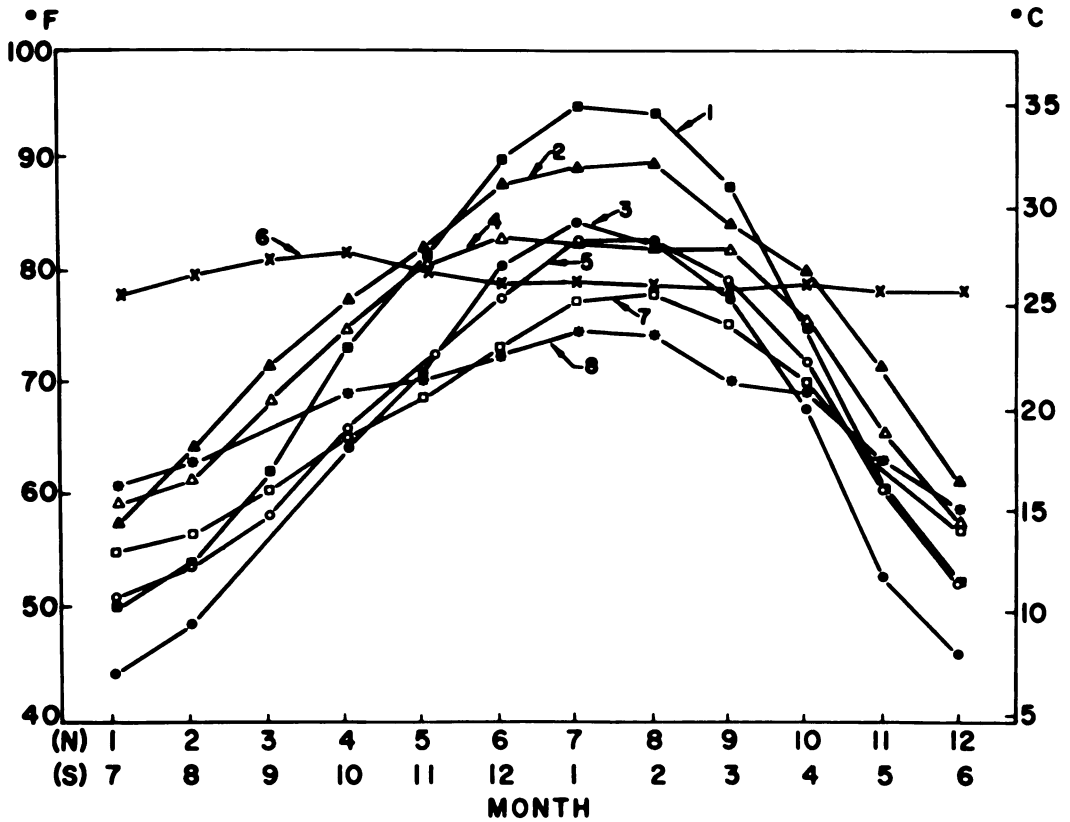

Fig. 9–29. Comparative seasonal soil-temperature regimes at a depth of 30 cm (12 inches) in citrus orchards in various regions of the world. Legends: (*N*) = Northern hemisphere; (*S*) = Southern hemisphere. Curve No. 1 = Thermal, California; No. 2 = Weslaco, Texas; No. 3 = Lindsay, California; No. 4 = Orlando, Florida; No. 5 = Riverside, California; No. 6 = Palmira, Colombia; No. 7 = Ventura, California; and No. 8 = Nelspruit, Republic of South Africa. The data for Palmira are for the 30 cm depth in table 9–17, and for Nelspruit are for a 35 cm depth calculated from thermograph tracings for the 1939–1940 season (Marloth, 1949). The U.S. data are from thermograph tracings obtained in missing tree spaces in Valencia orange orchards 3 to 5 m tall and are means of four to eight years (see table 9–13 for Ventura and Lindsay locations). The U.S. data are from University of California Agricultural Experiment Station Project 2120, supported in part by U. S. Department of Agriculture Contract No. 12–14–100–6873(34) (Reuther and Nauer, 1972).

The data summarized in table 9–13 indicate that, as would be expected, there is considerable variation from season to season in soil temperatures in a specific citrus orchard. Close inspection of these data reveals that monthly mean soil temperature at 30 cm in April varied during an eight year period between 15.9° C in 1956 and 20.8° C in 1959 in an orchard near Ventura, California. In an orchard near Lindsay, California, the comparable range was from 14.2° C in 1958 to 20.5° C in 1959. Such differences in soil temperature from season to season and the associated climatic differences contribute strongly to observed seasonal phenological variations, e.g., the dispersion of mid-bloom dates shown in table 9–3.

The data presented in figures 9–30, 9–31, and 9–32 indicate the dynamic temperature gradients always present in the principal root zone of citrus trees growing under orchard condition in deep, well-drained soils in subtropical climates. During the warmer months, when daily radiant energy gain at the surface exceeds loss, soil temperature decreases with depth; during the coldest months, when daily loss exceeds gain, temperature increases with depth. Another characteristic of soil temperature profiles is shown by this citrus orchard data. The times that seasonal monthly mean soil temperature maxima and minima occur coincide closely with those of the air temperature at shallow depths, but they lag behind at progressively greater depths. Thus, at Anaheim, Cali-

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Table 9–13
VARIATIONS FROM YEAR TO YEAR IN MONTHLY MEAN SOIL TEMPERATURES AT 30 CM DEPTH IN CALIFORNIA CITRUS ORCHARDS

	Temperatures (° C)											
Year	January	February	March	April	May	June	July	August	September	October	November	December
						VENTURA						
1955	....	....	....	16.7	17.8	22.2	23.9	25.0	23.6	19.2	15.3	12.2
1956	10.9	10.3	14.4	15.9	18.6	21.7	24.2	23.6	22.5	20.3	18.3	14.2
1957	11.4	13.3	15.9	17.8	21.1	25.0	27.2	27.2	25.6	22.0	16.4	15.3
1958	14.7	15.9	15.9	20.0	23.3	25.6	26.7	27.8	26.2	24.2	19.2	17.0
1959	15.9	14.7	19.7	20.8	20.8	23.3	26.7	26.7	25.0	22.5	19.7	16.4
1960	12.0	14.7	17.2	20.0	21.1	23.3	25.0	25.0	24.4	20.8	15.0	12.5
1961	14.2	15.0	15.9	18.9	20.0	22.5	25.0	25.3	23.1	20.8	15.6	11.7
1962	12.0	12.5	13.1	18.9	21.1	22.2	24.0	24.0	23.6	20.0	16.7	13.9
Mean	13.0	13.7	16.0	18.6	20.7	23.2	25.4	25.8	24.2	21.2	17.0	14.2
						LINDSAY						
1955	....	....	....	16.4	21.3	25.9	28.1	29.2	25.9	20.3	11.7	9.8
1956	8.8	6.4	14.4	16.4	20.5	24.4	26.7	23.9	23.6	19.2	10.9	7.5
1957	6.7	10.9	14.7	18.7	21.1	27.5	28.9	28.1	26.2	19.4	11.1	7.2
1958	6.1	8.9	9.5	14.2	22.0	26.2	29.4	29.7	24.4	20.8	11.1	6.1
1959	7.2	8.1	14.7	20.5	22.8	28.3	31.1	30.3	25.6	22.0	12.2	7.5
1960	6.4	9.5	14.7	18.9	22.5	30.3	30.9	28.6	26.5	19.2	12.2	7.5
1961	6.1	10.6	13.3	19.2	21.7	27.0	30.6	30.9	25.6	19.2	10.9	8.9
1962	5.9	10.3	12.2	20.0	22.8	27.5	29.2	25.9	26.2	20.0	13.3	7.8
Mean	6.7	9.2	13.3	18.0	21.9	27.1	29.3	28.3	25.4	20.0	11.7	7.8

Source: University of California Agricultural Experiment Station Project 2120, supported in part by U. S. Department of Agriculture Contract No. 12-14-100-6873-34 (Reuther and Nauer, 1972).

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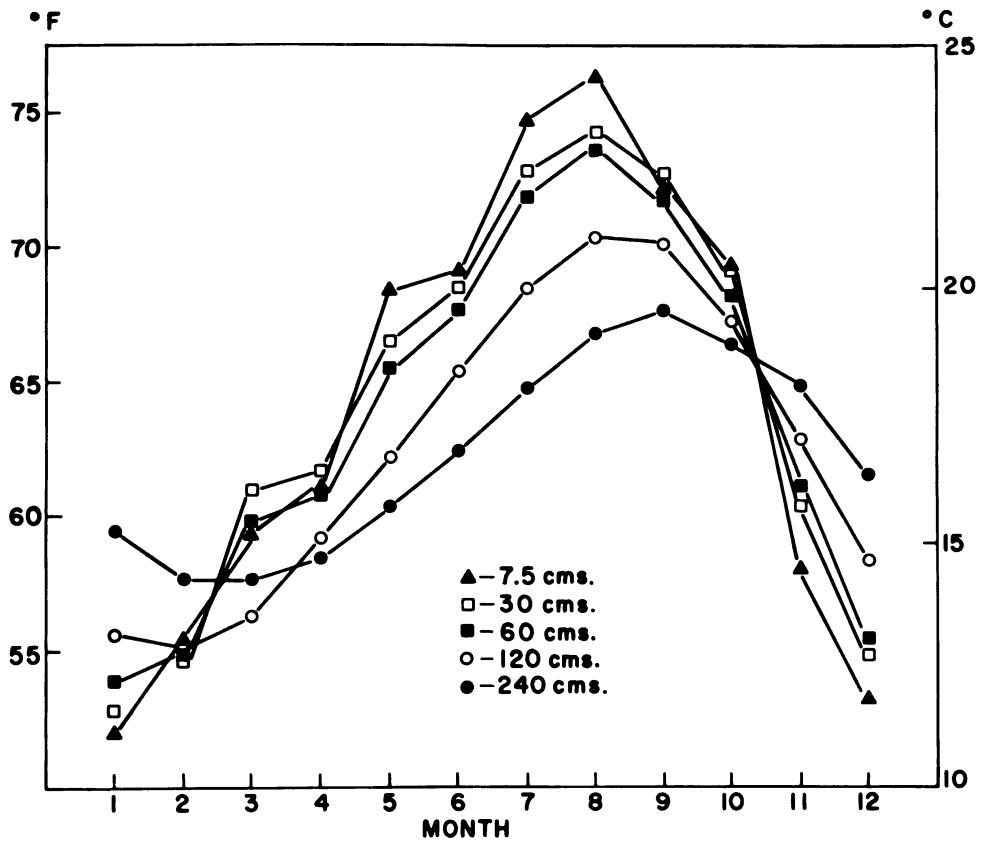

Fig. 9–30. Influence of depth on seasonal-temperature regimes in a citrus orchard near Anaheim, California (33° 50' N. latitude; elevation, 48 m). The sensors were located in an irrigated middle kept free of weeds between rows of mature Valencia orange trees about 4 m tall, and hence in the least shaded part of the orchard. The mean monthly temperatures plotted were calculated from daily thermograph tracings for the 7.5 and 30 cm depths, and from weekly 7:00 a.m. thermometer readings for the remaining deeper depths. The data were collected during the four year 1939–1943 period. (After Bliss, 1944.)

fornia the maximum and minimum temperatures at 7.5 cm occurs in August and January, but at eight feet they occur in September and February. This lag is shown even more clearly by the data presented in tables 9–14 and 9–15 and figures 9–31 and 9–32. The data in figure 9–30 also show that the major portion of the root system of the citrus trees in the Anaheim, California, orchard was at 15° C or lower during most of the period from mid-November through mid-March, since Bliss (1944) found only about 15 per cent of the roots occurred below a depth of 75 cm (30 inches) and about 2 per cent below a depth of 105 cm (42 inches) in this orchard. In contrast, the data of figure 9–31 and other data by DuCharme (1971) indicate that in most Florida citrus orchards, virtually the entire root system remains above 15° C throughout the year.

Among the important factors influencing soil temperature under cultivated conditions is the amount of shading provided by the crop's branch and leaf canopy and certain cultural factors. Thus, in an evergreen citrus orchard the density and distribution of the tree canopies, fallen leaves and other litter, cover crops, weeds, wind breaks, mulches, and similar factors vary over time and space. Such shielding or insulating factors moderate soil temperature mainly by shading the soil surface from direct solar radiation (reducing heat gain) and interfering with long wave back radiation (reducing heat loss) from it (Brooks, 1969). The soil temperature data summarized in figures 9–33 and 9–34 and tables 9–14 and 9–15 illustrate this effect in experimental plots comparing an unirrigated bare soil kept free of all vegetation by herbicide treatment and a sod

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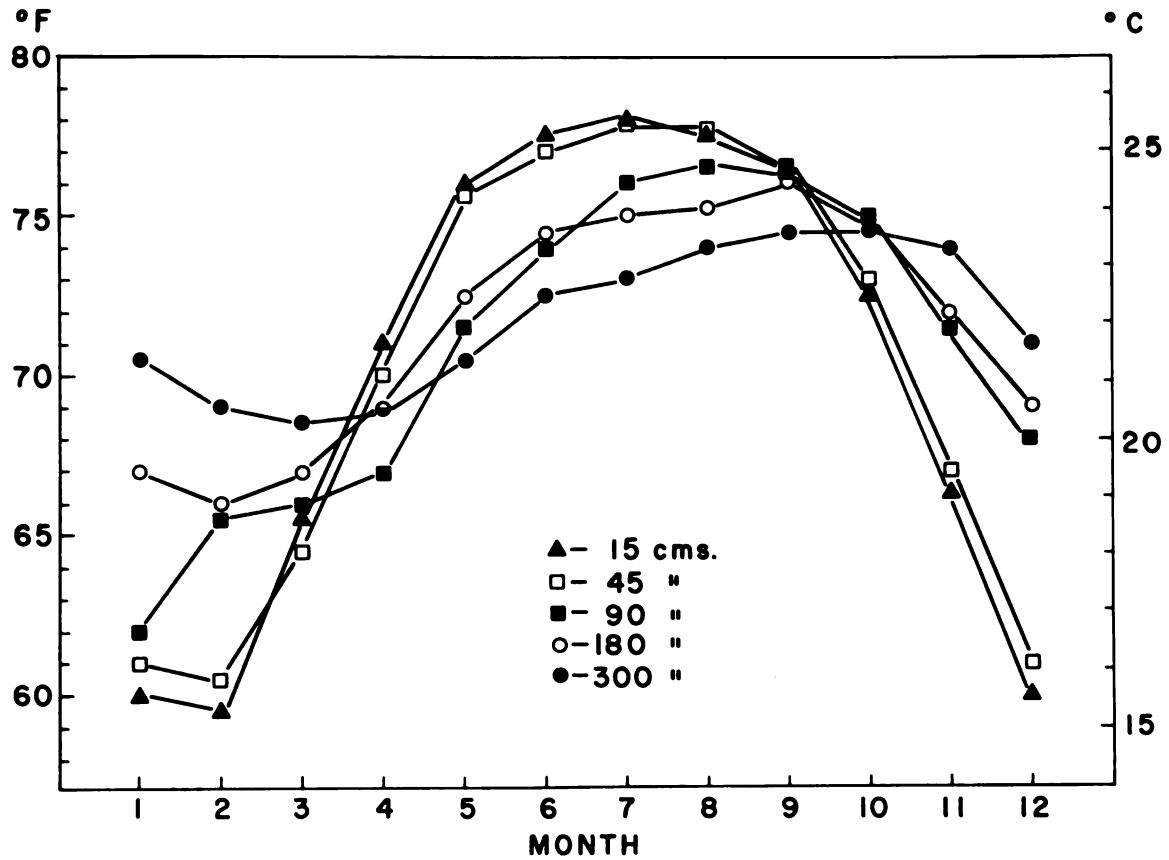

Fig. 9–31. Seasonal soil-temperature regimes (monthly means for the 1962–67 period) in relation to depth in the shade of a citrus tree in an orchard at the University of Florida Agricultural Research and Education Center, Lake Alfred, Florida. Latitude 28° 06′ N, elevation 55 m. (After DuCharme, 1971.)

covered soil maintained by periodic irrigation and mowing. The site is a well-drained loam soil of alluvial origin (Ramona series) adjacent to the University of California Citrus Research Center weather station (Field 9) at Riverside, California. The thermistor sensors in armored waterproof cables are permanently buried at the indicated depths in the center of plots about 6 meters square separated by 30 meters of unirrigated, uncultivated soil. Temperatures are recorded hourly by a scanning digital thermometer. Natural rainfall is confined to the carefully leveled surface of these plots by means of a small ridge of soil constructed around the perimeter of each plot.

Under typical clean culture (see chap. 3) conditions in California citrus orchards, the proportion of the soil surface fully or partially shaded by tree canopy would vary from a few per cent in a one- or two-year-old orchard to over 90 per cent in a vigorous twenty-five or thirty-year-old closely planted orchard. This latter condition would approach the effect of a dense sod cover in moderating soil temperature. In fact, soil temperatures in the sod plot closely approximate measurements made at comparable depths in a nearby experimental dense citrus orchard (Field 7) planted in 1917. Of course, both the sod plot and the orchard are irrigated frequently, and this also moderates soil temperature appreciably by increasing the soil's specific heat and thermal conductivity and by cooling or warming, depending on the temperature of the irrigation water in relation to that of wetted soil. Thus the data summarized in figures 9–33 and 9–34 and tables 9–14 and 9–15 approximate the extreme range of soil temperatures that could occur in a climate like Riverside's underneath a tree canopy in a young clean cultivated orchard irrigated along the tree line only, and compared to a site three or four meters away in the

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Table 9–14

MEAN MONTHLY MAXIMUM AND MINIMUM TOPSOIL TEMPERATURES AT RIVERSIDE, CALIFORNIA IN RELATION TO DEPTH AND TREATMENT

Month, 1969	Monthly Mean	Temperatures (° C)							
		Soil Depth (Cm) and Treatment							
		5		10		20		30	
		Bare	Sod	Bare	Sod	Bare	Sod	Bare	Sod
January	Maximum	15.1	12.6	13.6	12.3	12.8	12.0	12.8	12.0
	Minimum	8.4	9.8	9.6	10.3	11.3	11.0	11.7	11.3
February	Maximum	13.5	12.3	12.4	11.9	11.6	11.5	11.3	11.5
	Minimum	7.4	8.9	8.2	9.6	9.6	10.3	10.1	10.7
March	Maximum	18.4	15.1	16.7	14.5	14.6	13.6	14.0	13.4
	Minimum	8.8	10.8	10.1	11.5	11.6	12.2	12.2	12.5
April	Maximum	25.2	19.9	23.2	19.0	20.9	17.7	19.8	17.3
	Minimum	14.7	15.0	15.9	15.7	17.4	16.2	17.9	16.4
May	Maximum	28.9	23.6	27.3	22.6	25.0	21.2	23.9	20.7
	Minimum	19.1	18.6	20.2	19.1	21.5	19.5	21.8	19.7
June	Maximum	30.4	24.3	28.5	23.5	26.5	22.5	25.5	22.1
	Minimum	21.2	20.2	22.2	20.7	23.3	21.1	23.6	21.2
July	Maximum	37.3	28.2	35.1	27.1	32.2	25.7	30.8	25.2
	Minimum	25.6	23.0	26.9	23.6	28.3	24.1	28.3	24.2
August	Maximum	37.9	27.8	35.9	27.0	33.5	26.0	32.3	25.7
	Minimum	26.8	23.4	28.2	24.0	29.8	24.6	30.2	24.8
September	Maximum	33.5	24.7	31.9	24.3	30.1	23.7	29.1	23.6
	Minimum	23.8	21.2	25.1	21.9	26.9	22.6	27.2	22.9
October	Maximum	24.9	18.5	23.8	18.6	22.8	18.7	22.2	18.9
	Minimum	18.3	15.9	16.9	16.8	20.2	17.8	20.7	18.3
November°	Maximum	21.2	15.9	20.0	15.7	18.7	15.7	18.6	15.9
	Minimum	11.9	12.9	13.5	13.6	16.7	14.7	17.5	15.3
December°	Maximum	14.2	9.9	13.1	9.9	12.1	10.0	12.3	10.4
	Minimum	5.1	6.9	6.8	7.8	10.3	9.0	11.2	9.7

Source: Reuther and Nauer (1972).
° 1968.

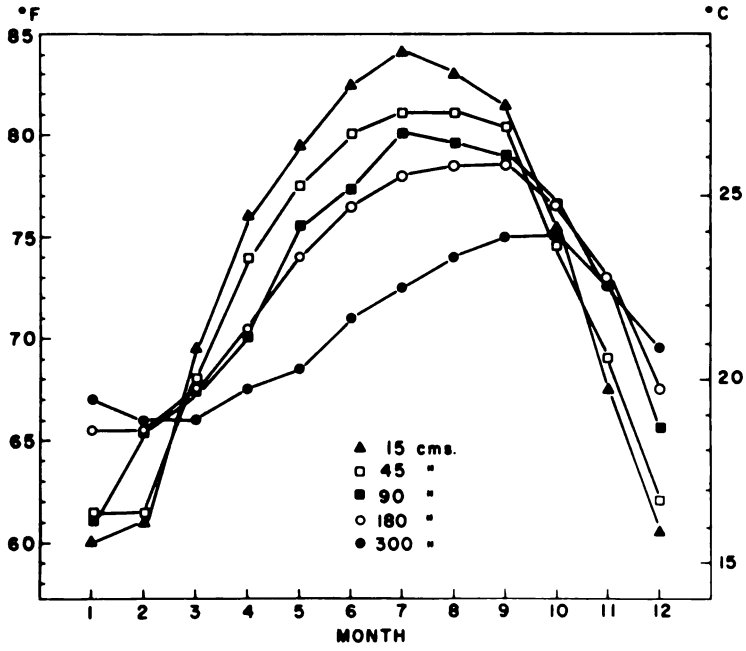

Fig. 9–32. Seasonal soil-temperature regimes (monthly means for the 1962–67 period) in relation to depth in unshaded bare soil at the University of Florida Agricultural Research and Education Center, Lake Alfred, Florida. Latitude 28° 06′ N; elevation, 55 m. (After DuCharme, 1971.)

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Table 9–15
MEAN MONTHLY MAXIMUM AND MINIMUM SUBSOIL TEMPERATURES AT RIVERSIDE, CALIFORNIA IN RELATION TO DEPTH AND TREATMENT

Month, 1969	Monthly Mean	Temperature (° C)							
		Soil Depth (Cm) and Treatment							
		50		100		200		300	
		Bare	Sod	Bare	Sod	Bare	Sod	Bare	Sod
January	Maximum	13.0	12.1	13.9	12.9	16.5	15.6	18.8	17.5
	Minimum	12.4	11.8	13.7	12.8	16.4	15.5	18.8	17.3
February	Maximum	11.4	11.6	12.2	12.7	15.3	15.0	17.6	16.5
	Minimum	11.1	11.3	10.6	12.5	15.1	14.9	17.4	16.4
March	Maximum	13.2	13.1	13.3	13.3	14.6	14.7	16.6	16.0
	Minimum	12.7	12.8	13.0	13.1	14.5	14.6	16.4	15.8
April	Maximum	18.6	16.8	17.2	16.1	16.3	15.7	16.7	16.1
	Minimum	18.1	16.5	17.0	15.9	16.1	15.6	16.5	16.0
May	Maximum	22.4	19.9	20.4	18.7	18.5	17.4	17.8	17.1
	Minimum	21.8	19.5	20.1	18.4	18.3	17.2	17.7	16.9
June	Maximum	24.3	21.6	22.7	20.8	20.7	19.3	19.3	18.4
	Minimum	23.8	21.2	22.5	20.6	20.5	19.1	18.8	18.2
July	Maximum	28.9	24.4	26.1	23.0	22.7	20.7	20.6	19.5
	Minimum	28.4	24.0	25.9	22.8	22.5	20.6	20.5	19.4
August	Maximum	30.9	25.2	28.6	24.4	25.1	22.4	22.4	20.8
	Minimum	30.4	24.9	28.4	24.3	24.9	22.2	22.2	20.7
September	Maximum	28.5	23.5	27.6	23.6	25.7	22.8	23.6	21.7
	Minimum	28.0	23.2	27.5	23.5	25.4	22.6	23.4	21.5
October	Maximum	22.9	19.5	23.9	21.0	24.1	22.0	23.6	21.7
	Minimum	22.6	19.1	23.7	20.7	23.3	21.6	23.4	21.6
November°	Maximum	19.1	16.5	20.6	18.3	21.9	19.9	22.3	20.7
	Minimum	18.7	16.2	20.4	18.1	21.8	19.7	22.1	20.6
December°	Maximum	13.3	11.3	15.9	13.9	19.1	17.8	20.6	19.2
	Minimum	12.8	11.0	15.6	13.7	19.0	17.6	20.0	19.1

Source: Reuther and Nauer (1972).
° 1968.

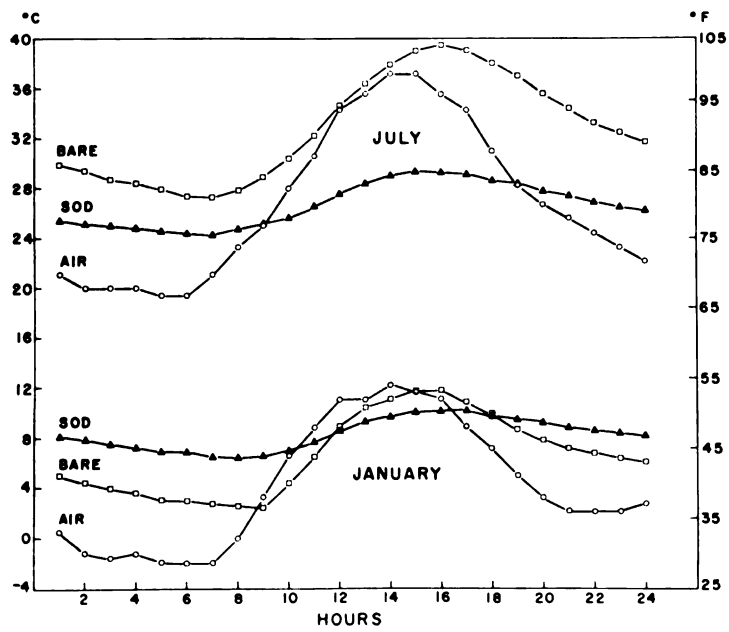

Fig. 9–33. Comparison of the diurnal temperature regimes of irrigated sod covered and unirrigated bare soil at 5 cm depth on January 30 and July 30, 1969 at Riverside, California. (After Reuther and Nauer, 1972.)

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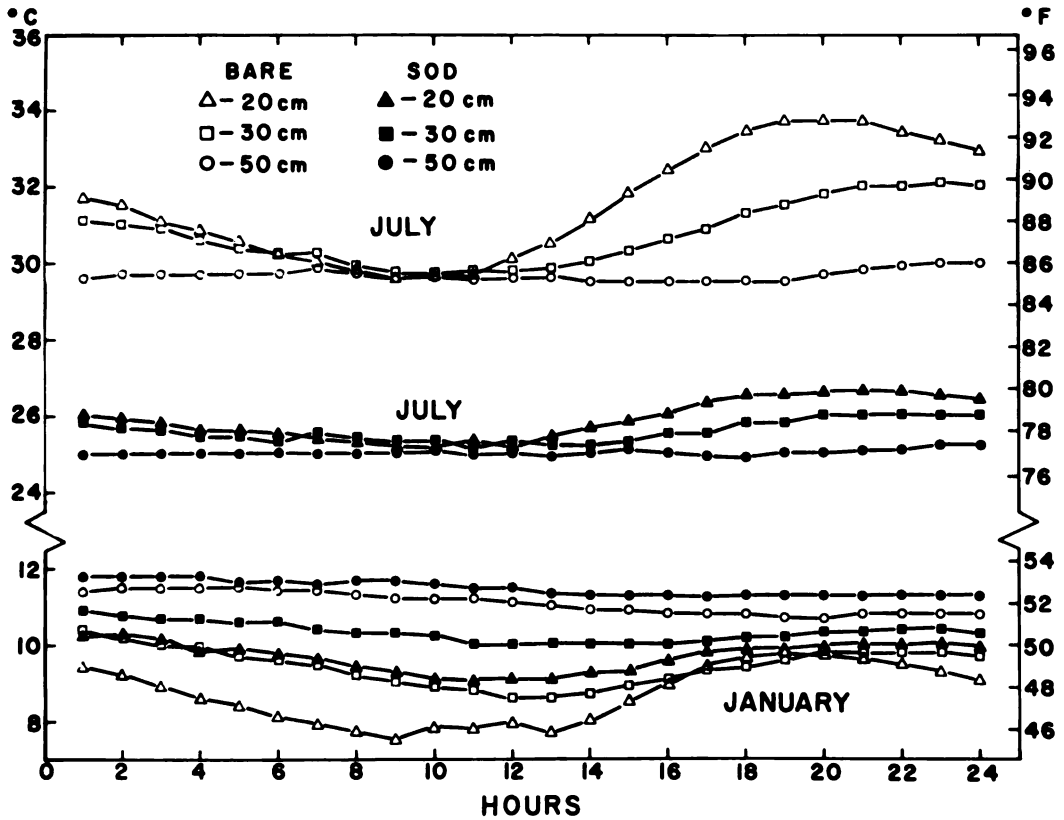

Fig. 9–34. Comparison of diurnal temperature regimes of irrigated sod covered and unirrigated bare soil on January 30 and July 30, 1969 at various depths at Riverside, California. (After Reuther and Nauer, 1972.)

bare unirrigated middle. Of course, in most soils, there would be some capillary movement of irrigation water in the subsoil toward the unirrigated middle, and this would moderate the temperature of the deeper layers of the bare soil appreciably.

The data presented in figure 9–33 indicate the influence of soil cover and irrigation on the relationship of ambient soil temperature near the surface to ambient air temperature during a typical clear, hot, long day in midsummer and clear, cool, short day in midwinter. The data presented in figure 9–34 and tables 9–14 and 9–15 further emphasize the moderating influence of soil cover and irrigation on both the daily and seasonal amplitude of soil temperature throughout the profile penetrated by citrus roots.

The marked shielding influence of a dense tree canopy on heat flux in the soil is shown without the complicating influence of differential irrigation treatment in figures 9–31 and 9–32. The shaded soil was in a thirty-five-year-old citrus orchard on deep, very sandy soil (Lakeland series); the unshaded soil was a comparable nearby bare area located about 30 meters from any shading influence of citrus trees, and kept free of all vegetation. Both received only natural rainfall (DuCharme, 1971).

The moderating influence of cover, irrigation, rainfall, and related factors on soil temperature can have significant favorable and unfavorable influences on tree behavior and vulnerability to temperature extremes. Some of these factors may be of considerable importance in making a wise choice of cultural practices involving cover crops, mulches, irrigation, and weed control, especially in young orchards.

Table 9–16 offers a more detailed comparison between the soil-temperature profile in the principal root zone of tree crops such as citrus in (1) a tropical location near the equator and (2) a subtropical location fairly typical of the world's major citrus-growing regions. From these data, it can be deduced that the amplitudes of seasonal variation and the steepness of gradients with depth will diminish as latitudes become lower. Thus at the equator heat flux in the soil becomes

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Table 9–16
COMPARISON OF SEASONAL SOIL TEMPERATURE REGIMES UNDER SOD IN SUBTROPICAL CALIFORNIA AND TROPICAL COLOMBIA

Location* and Depth, (Cm)		Mean Monthly Temperature (°C)											
		1	2	3	4	5	6	7	8	9	10	11	12
R	10	11.3	10.8	13.0	17.4	20.4	22.4	24.2	25.5	23.1	17.7	14.6	8.9
P	10	23.5	24.0	24.5	24.7	24.3	23.7	23.7	23.7	23.7	23.9	23.7	23.3
R	20	11.5	10.9	12.9	17.0	20.4	21.8	24.9	25.3	23.2	18.3	15.2	9.5
P	20	25.3	26.0	26.5	26.9	26.0	25.4	25.4	25.2	25.4	25.6	25.4	24.9
R	30	11.7	11.1	13.0	16.9	20.2	21.7	24.7	25.3	23.3	18.6	15.6	10.1
P	30	26.0	26.6	27.1	27.5	26.8	26.1	26.3	26.1	26.1	26.3	25.8	25.8
R	50	12.0	11.5	13.0	16.7	19.7	21.4	24.2	25.1	23.3	19.3	16.4	11.2
P	50	26.0	26.5	27.0	27.3	26.9	27.3	26.3	26.5	26.1	26.5	26.4	25.9
R	100	12.9	12.6	13.2	16.0	18.6	20.7	22.9	24.4	23.6	20.9	18.2	13.8
P	100	26.1	26.0	27.0	27.1	26.9	26.5	26.4	26.5	26.5	26.5	26.3	26.2
R	200	15.6	15.0	14.7	15.7	17.3	19.2	20.7	22.3	22.7	21.8	19.8	17.8
P	150	26.1	26.3	26.7	26.8	26.8	26.4	26.4	26.4	26.5	26.3	26.5	26.3
R	300	17.4	16.5	15.9	16.1	17.0	18.3	19.5	20.8	21.6	21.7	20.7	19.2
P	300	26.4	26.5	26.5	26.3	26.4	26.4	26.4	26.5	26.5	26.3	26.5	26.3

* R = Riverside, California, University of California CRC weather station, 33° 57′ N. latitude, elev. 250 m. Data from thermister probes permanently installed in soil in the center of a 20 × 20 foot irrigated sod plot recorded hourly by a scanning digital thermometer. Monthly means calculated from sums of daily mean maxima and minima divided by 2. Data are for the one-year period from November, 1968 through October, 1969.

P = Palmira, Colombia, 3° 31′ N. latitude, elev. 1,006 m. Data from the rainfed sodded weather station enclosure of the Instituto Colombiano Agropecuario, and furnished through the courtesy of Dr. Alfredo Leon. Temperatures obtained with a mercury thermometer inserted in soil in a plastic probe fitting snugly inside a plastic tube-lined access hole, were read daily between 7:00 and 8:00 A.M., and hence might vary as much as 2° from the diurnal mean at the 10 cm depth, but less than 1° at deeper depths. Data are for the one-year period from December, 1966 through November, 1967.

minimal, and the thermal environment of the root system of a citrus orchard changes very little with season, being virtually homogeneous with depth.

Soil Temperature Influences

Most of the available evidence suggests that the root system of a citrus tree responds to temperature in much the same way as does the top, although precise studies have not been made. The data of Labanauskas *et al.* (1958), summarized in figure 9–35, show the typical response of citrus seedlings grown under various rigidly controlled soil temperatures but with tops all exposed to uniform favorable greenhouse growing temperatures (around 20° C at night and up to 32° C during the day). Soil temperature was controlled by immersing containers in chilled or heated water baths, with vermiculite mulching and pressed wood shielding to minimize radiation exchange of heat between the seedlings tops and the water bath and containers.

These studies indicated that after thirteen weeks at differential soil temperatures, seedlings at 7° C remained at about pretreatment size, those at 14° C grew slightly, and those at 21° C, 28° C, and 35° C all grew fairly rapidly. In relation to pretreatment size, rough lemon and Koethen sweet orange made the most growth at a soil temperature of 14° C as measured by mean dry weight gain of fifteen pots of two plants each. Among those making the least growth at 14° C was Cleopatra mandarin, which fell in the same group at trifoliate orange, Troyer citrange, grapefruit and *Citrus pectinifera* (data not shown) in this respect. Sour orange was intermediate in its growth at 14° C.

The mean dry weights of the root systems obtained after thirteen weeks of differential treatment suggest that root growth (fig. 9–36) was slightly reduced at 35° C as compared to 28° C, but variability among replications was somewhat too large to conclude definitely that this trend was real. Total growth as indicated by the combined weight of both tops and roots was about the same at 35° C as at 28° C, but, with the exception of rough lemon, was significantly smaller at 21° C than at 28° C. For rough lemon, dry weight at 21° C was about equal to that at 28° C. Thus, these data of Labanauskas *et al.* (1958) tend to show that the effect of root temperature, when

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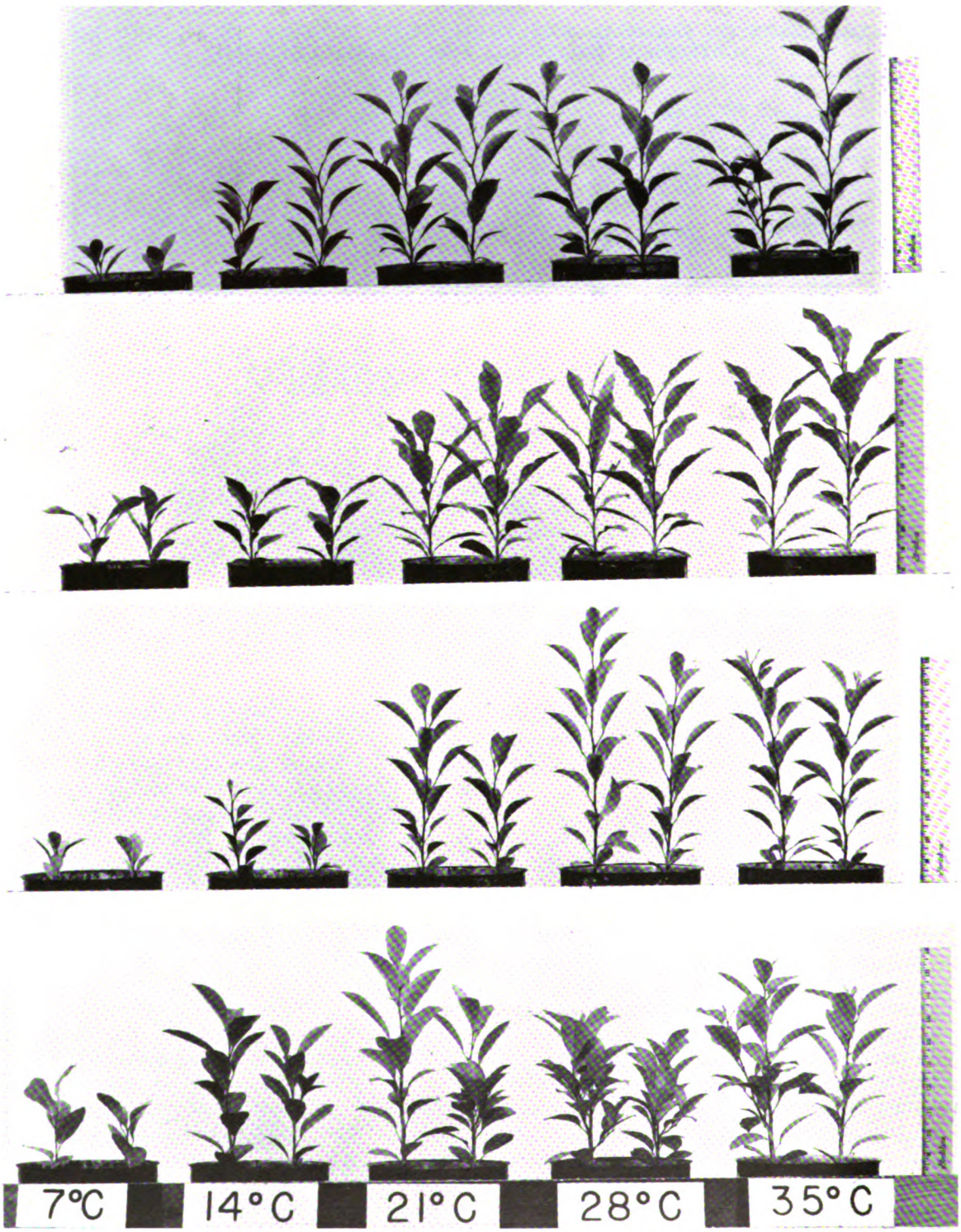

Fig. 9–35. Influence of soil temperature on vegetative growth of seedlings of several citrus species. From top to bottom as follows: Koethen sweet orange (*C. sinensis*); Standard sour orange (*C. aurantium*); Cleopatra mandarin (*C. reticulata*); and rough lemon (*C. limon*). From Labanauskas *et al.* (1958).

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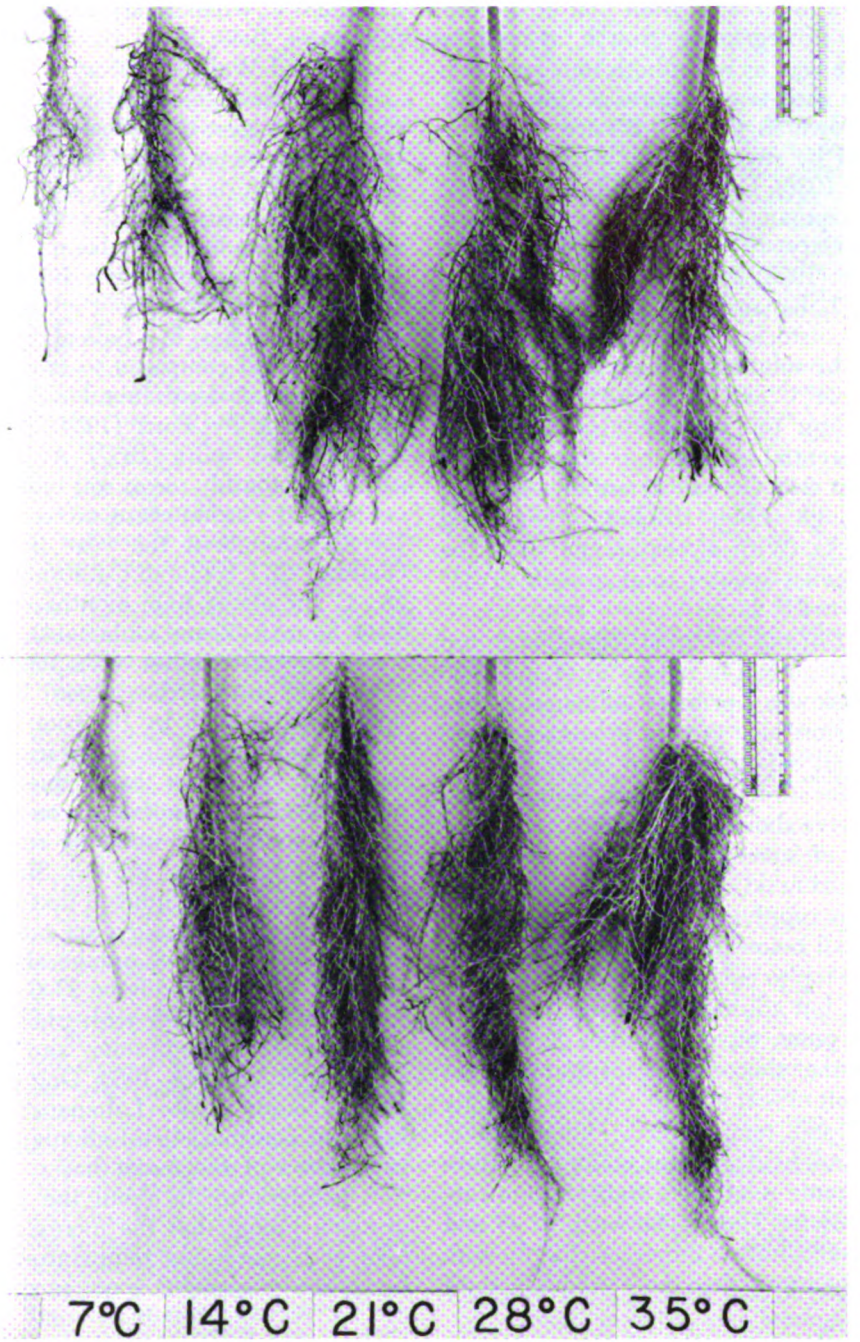

Fig. 9–36. Influence of soil temperature on root growth of Standard sour orange (top) and rough lemon (bottom) seedlings. From Labanauskas *et al.* (1958).

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maintained at a differential from that of the top, affects volume of vegetative growth, at least, in about the same way as when both tops and roots are exposed to such temperatures (Girton, 1927). The trends shown in figure 9–35 are similar to those obtained by several other workers (Haas, 1936; Halma, 1936; DeWolfe and Klotz, 1957; Liebig and Chapman, 1963; Ongun and Wallace, 1958*a*, 1958*b*; Cary, 1970). However, the growth data of Naudé (1958) are somewhat at variance with those of Labanauskas *et al.* (1958). Naudé used various rootstocks grafted to Eureka lemon tops growing in solution cultures controlled to provide 18° C, 24° C, and 32° C root temperatures, but with uniform top temperatures. After 4½ months of differential treatment, he found greater total growth at 24° C than at either 18° C or 32° C with rough lemon, trifoliate orange, and grapefruit stocks. With sweet orange stock, he obtained somewhat greater total growth at 32° C as compared to 24° C.

Whether or not the great reduction in top and root growth shown in figures 9–35 and 9–36 at 14° C and below is a primary influence of temperature *per se* on such growth processes as cell division and cell enlargement in citrus tissue is not clear. Various studies (Cameron, 1940; Elfving *et al.*, 1972*b*) have shown that the citrus root system, like that of some other woody perennials (Kramer and Kozlowski, 1960) is sharply restricted in its ability to supply water to the top as soil temperatures fall below 15° C. Thus the growth response of the top to cold soil may be due partly to water stress, but additional research is needed to clarify this point. Several studies have been made showing that short-term transpirational use of water per unit of leaf area by citrus is strongly influenced by soil temperature. When aboveground factors are held constant, soil temperature has about the same relation to transpiration rate as does top growth. That is, between 0° C and about 15° C, transpiration increases sharply with increasing temperature, then more gradually until about 35° C, when it may begin to decline slightly (Cameron, 1940; Haas, 1936; Bialoglowski, 1936; Ongun and Wallace, 1958*c*).

Studies concerned with root distribution of citrus suggest that the lower density of roots below one meter found in deep, well drained soils in California than in Florida may be due, in part at least, to soil temperature. For example, the studies of Cahoon *et al.* (1956, 1961, 1964) and Bliss (1944) all indicated that less than 5 per cent of the citrus root system is found below 100 cm (40 inches) in a typical deep, well-drained California soil compared to around 25 to 33 per cent below this depth found in deep, well-drained Florida soils by Ford (1954, 1959), and Ford, Reuther, and Smith (1957). Available data indicate that monthly mean soil temperatures at 100 cm in most Florida citrus orchards remain above 15° C throughout the year (figure 9–31; DuCharme, 1971, while in California they fall below 15° C for about four months each year (Bliss, 1944; figure 9–30 and table 9–14).

Several studies (Chapman and Parker, 1942; Roy and Gardner, 1945) have shown that uptake of nitrogen by the root system of citrus trees is more active in the warmer months than in winter. No doubt this is due not only to the influence of soil temperature on the active nitrogen accumulation process by roots, but also on translocation and on growth. Short-term studies by Wallace (1953), indicate that although significant amounts of nitrogen are taken up by citrus roots at 9° C, rate of uptake about doubles for each 10° C increase above 9° C until about 30° C is reached. Studies with phosphorous, potassium, calcium, magnesium, and other nutrients (Smith and Wallace, 1956; Ongun and Wallace, 1958*a*; Naudé, 1958; Labanauskas *et al.*, 1958; Roy and Gardner, 1945) all suggest that the accumulation of the major bases is influenced by root temperature in about the same manner as nitrogen except that the increase in rate of uptake with increasing temperature (in the range favorable for growth) is not so steep.

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LITERATURE CITED

ARNOLD, C. Y. 1960. Maximum-minimum temperatures as a basis for computing heat units. Proc. Amer. Soc. Hort. Sci. **76**:682–692.

AYALON, S., and S. P. MONSELISE. 1960. Flower bud induction and differentiation in the Shamouti orange. Proc. Amer. Soc. Hort. Sci. **75**:216–21.

BAIN, F. M. 1949. Citrus and climate. Calif. Citrog. **34**: 382, 412–14, 426, 448–49.

BAIN, J. M. 1958. Morphological, anatomical, and physiological changes in the developing fruit of the Valencia orange, *Citrus sinensis* (L.) Osbeck. Austral. Jour Bot. **6**:1–24.

BARNARD, C. 1946. Climate and the distribution of citrus. Aust. Inst. Agr. Sci. Jour. **12**:134–38.

BARTON, L. V. 1943. The storage of citrus seeds. Contr. Boyce Thompson Inst. **13**:47–55.

BEUTEL, J. A. 1964. Soil moisture, weather and fruit growth. Calif. Citrog. **49**:372.

BIALOGLOWSKI, J. 1936. Effect of extent and temperature of roots on transpiration of rooted lemon cuttings. Proc. Amer. Soc. Hort. Sci. **34**:96–102.

BLANPIED, G. D. 1964. The relationship between growing season temperatures, bloom dates and the length of the growing season of Red Delicious apples in North America. Proc. Amer. Soc. Hort. Sci. **84**: 72–81.

BLISS, D. E. 1944. Air and soil temperatures in a California citrus orchard. Soil Sci. **58**:259–74.

BORTHWICK, H. A. 1957. Light effects on tree growth and seed germination. Ohio Jour. Sci. **57**:357–64.

BOSWELL, S. B., L. N. LEWIS, C. D. MCCARTY, and K. W. HENCH. 1970. Tree spacing of 'Washington' navel orange. Jour. Amer. Soc. Hort. Sci. **95**:523–28.

BOYNTON, D., and O. C. COMPTON. 1943. Effect of oxygen pressure in aerated nutrient solution on production of new roots and on growth of roots and tops by fruit trees. Proc. Amer. Soc. Hort. Sci. **42**:53–58.

BROOKS, F. A. 1959. An introduction of physical microclimatology. Univ. of Calif., Davis. 264 pp.

——— 1964. Agricultural needs for special and extensive observations of solar radiation. Bot. Rev. **30**:63–291.

BROWN, D. S. 1952. Climate in relation to deciduous fruit production in California. V. The use of temperature records to predict the time of harvest of apricots Proc. Amer. Soc. Hort. Sci. **60**:197–203.

——— 1953. Climate in relation to deciduous fruit production in California. VI. The efficiencies of different temperatures for the development of apricot fruit. Proc. Amer. Soc. Hort. Sci. **62**:173–83.

CAHOON, G. A., R. B. HARDING, and D. B. MILLER. 1956. Declining root systems. Calif. Agr. **10**(9):3, 12.

CAHOON, G. A., M. R. HUBERTY, and M. J. GARBER. 1961. Irrigation frequency effects on citrus root distribution and density. Proc. Amer. Soc. Hort. Sci. **77**: 167–72.

CAHOON, G. A., L. H. STOLZY, M. J. GARBER, and E. S. MORTON. 1964. Influence of nitrogen and water on the root density of mature Washington navel orange trees. Proc. Amer. Soc. Hort. Sci. **85**:224–31.

CALAVAN, E. C., C. N. ROISTACHER, and E. M. NAUER, 1972. Heat treatment of buds for elimination of citrus viruses. Plant Dis. Reptr. **56**:976–98.

CAMACHO-BUSTOS, S. 1972. The response of four citrus species to flooding under greenhouse conditions. M.S. thesis, on file at Dept. of Plant Sciences, Univ. of Calif., Riverside, Calif.

CAMERON, J. W., and H. B. FROST. 1968. Genetics, breeding and nucellar embryony. *In:* Reuther, W., L. D. Batchelor, and H. J. Webber (eds.), The Citrus Industry. Rev. ed. **2**:325–70. Univ. of Calif. Div. Agr. Sci. Berkeley, Calif.

CAMERON, S. H., R. T. MUELLER, and A. WALLACE. 1951. Measurement and chemical composition of the seasonal new growth of mature Valencia orange trees. Proc. Amer. Soc. Hort. Sci. **58**:11–13.

CAMERON, S. H. 1940. Influence of soil temperature on the role of transpiration of young orange trees. Proc. Amer. Soc. Hort. Sci. **38**:75–79.

CAMERON, S. H., R. T. MUELLER, A. WALLACE, and E. SARTORI. 1952. Influence of age of leaf, season of growth, and fruit production on the size and inorganic composition of Valencia orange leaves. Proc. Amer. Soc. Hort. Sci. **60**:42–50.

CAMP, A. F., H. MOWRY, and K. W. LOUCKS. 1933. The effect of soil temperature on the germination of citrus seeds. Amer. Jour. Bot. **20**:348–57.

CAPRIO, J. M. 1956. Analysis of the relation between regreening of Valencia oranges and mean monthly temperatures in Southern California. Proc. Amer. Soc. Hort. Sci. **67**:222–35.

CAREY, P. R. 1970. Growth, yield, and fruit composition of Washington navel orange cuttings as affected by root temperature, nutrient supply, and crop load. Hort. Res. **10**:20–23.

CASSIN, J., J. BOURDEAUT, A. FOUGUE, V. FURON, J. P. GAILLARD, J. LEBOURDELLES, G. MONTAGUT, and C. MOUREUIL. 1969. The influence of climate upon the blooming of citrus in tropical areas. *In:* H. D. Chapman (ed.) Proc. First Intern. Citrus Symp., **1**:315–23. Univ. of Calif. Riverside, Calif.

CHANDLER, W. H. 1958. Evergreen orchards. 2nd ed. Lea Febiger, Phila., Pa. 535 pp.

CHANEY, W. R., and T. T. KOZLOWSKI. 1971. Water transport in relation to expansion and contraction of leaves and fruits of Calamondin orange. Jour. Hort. Sci. **46**:71–81.

CHANG, JEN-HU. 1968. Climate and agriculture—an ecological survey. Aldine Publishing Co., Chicago, Ill. 304 pp.

CHAPMAN, H. D., and E. R. PARKER. 1942. Weekly absorption of nitrate by young, bearing orange trees growing out of doors in solution cultures. Plant Physiol. **17**:366–76.

COOPER, W. C., R. H. HILGEMAN, and G. K. RASMUSSEN. 1964. Diurnal and seasonal fluctuation of trunk growth of the Valencia orange as related to climate. Proc. Fla. State. Hort. Sci. **77**:101–106.

COOPER, W. C., A. PAYNADO, J. R. FURR, R. H. HILGEMAN, G. A. CAHOON, and S. B. BOSWELL. 1963. Tree growth and fruit quality of Valencia oranges in relation to climate. Proc. Amer. Soc. Hort. Sci. **82**:180–92.

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DeWolfe, T. A., and L. J. Klotz. 1957. The effect of soil temperature on the growth of citrus seedlings. Ann. Rept. Proj. **250**:1409–16. Unpublished data on file at Univ. Calif. Agr. Expt. Sta.

Downton, J., and R. O. Slayter, 1972. Temperature dependence of photosynthesis in cotton. Plant Physiol. **50**:518–22.

DuCharme, E. P. 1971. Soil temperature in Florida citrus groves. Univ. Fla. Agr. Expt. Sta. Tech. Bul. No. 747. 15 pp. Gainesville, Fla.

Eggert, F. P. 1960. The relation between heat unit accumulation and length of time required to mature McIntosh apples in Maine. Proc. Amer. Soc. Hort. Sci. **76**:98–105.

Elfving, D. C., and M. R. Kaufmann. 1972. Diurnal and seasonal effects of environment on plant water relations and fruit diameter of citrus. Jour. Amer. Soc. Hort. Sci. **97**:566–70.

Elfving, D. C., M. R. Kaufman, and A. E. Hall. 1972*a*. Interpreting plant water potential measurements with a model of the soil-plant-atmosphere continuum. Submitted to: Physiol. Plant.

——— 1972*b*. Interpreting plant water potential measurements under conditions of stress in the root environment. Submitted to: Physiol. Plant.

Elze, D. L. 1949. Germination of citrus seeds in relation to certain nursery practices. Palestine Jour. Bot. Rev. **7**:69–80.

Erickson, L. C. 1968. The general physiology of citrus. *In:* Reuther, W. L. D. Batchelor, and H. J. Webber, (eds.). The Citrus Industry. Rev. ed. **2**:86–126. Univ. Calif. Div. Agr. Sci., Berkeley, Calif.

Fawcett, H. S. 1929. Temperature experiments in germinating orange seeds. Calif. Citrog. **14**:515.

Fisher, D. V. 1962. Heat units and number of days required to mature some pome and stone fruits in various areas of North America. Proc. Amer. Soc. Hort. Sci. **80**:114–24.

Ford, H. W. 1964. The effect of rootstock, soil type, and soil pH on citrus root growth in soils subject to flooding. Proc. Fla. State Hort. Soc. **77**:41–45.

——— 1965. Bacterial metabolites that affect citrus root survival in soils subject to flooding. Proc. Amer. Soc. Hort. Sci. **86**:205–12.

Ford, H. W., W. Reuther, and P. F. Smith. 1957. Effect of nitrogen on root development of Valencia orange trees. Proc. Amer. Soc. Hort. Sci. **70**:237–44.

Furr, J. R., and W. W. Armstrong. 1956. Flower induction in Marsh grapefruit in the Coachella Valley, California. Proc. Amer. Soc. Hort. Sci. **67**:176–82.

Furr, J. R., W. C. Cooper, and P. C. Reese. 1947. An investigation of flower formation in adult and juvenile citrus trees. Amer. Jour. Bot. **34**:1–8.

Furr, J. R., and C. A. Taylor. 1939. Growth of lemon fruits in relation to moisture content of the soil. U. S. Dept. Agr. Tec. Bul. No. 640, 72 pp.

Gates, D. M. 1962. Energy exchange in the biosphere. Harper and Row, N.Y. 151 pp.

Girton, R. E. 1927. The growth of citrus seedlings as influenced by environmental factors. Univ. Calif. Pub. Agr. Sci. **5**:83–117.

Gonzalez-Sicilia, E. 1968. El cultivo de los agrios. Editorial Bello, Valencia, Spain. 814 pp.

Grable, A. R. 1966. Soil aeration and plant growth. Advan. in Agron. **18**:57–106.

Grant, T. J. 1957. Heat treatment for obtaining sources of virus-free citrus budwood. Proc. Fla. State Hort. Soc. **70**:51–53.

Greene, B.A., and J. F. Gerber. 1967. Radiant energy distribution in citrus trees. Proc. Amer. Hort. Sci. **90**: 77–85.

Haas, A. R. C. 1936. Growth and water losses in citrus as affected by soil temperature. Calif. Citrog. **21**:467, 479.

Halma, F. F. 1936. Effect of soil temperature on the growth of citrus. Proc. Amer. Soc. Hort. Sci. **33**: 67–69.

Harding, P. L. 1947. Quality in citrus fruits: Seasonal changes in relation to consumer acceptance of oranges, grapefruit, Temple oranges, and tangerines. Proc. Amer. Soc. Hort. Sci. **49**:107–15.

Harding, P. L., and D. F. Fisher. 1945. Seasonal changes in Florida grapefruit. U. S. Dept. Agr. Tech. Bul. No. 886, 100 pp.

Harding, P. L., and M. B. Sunday. 1949. Seasonal changes in Florida tangerines. U. S. Dept. Agr. Tech. Bul. No. 988, 59 pp.

Harding, P. L., J. R. Winston, and D. F. Fischer, 1940. Seasonal changes in Florida oranges. U. S. Dept. Agr. Tech. Bul. No. 753, 89 pp.

Hellmers, H. 1962. Temperature effect on optimum tree growth. *In:* Kozlowsky, T. T. (ed.). Tree growth. pp. 275–88. Ronald Press, N.Y.

——— 1966. Growth response of redwood seedlings to thermoperiodism. For. Sci. **12**:276–83.

Hilgeman, R. H. 1941. Studies of the ripening of Marsh grapefruit in Arizona. Univ. of Ariz. Agr. Exp. Sta. Tech. Bul. **89**:95–168.

——— 1966. Effect of climate of Florida and Arizona on grapefruit enlargement and quality: apparent transpiration and internal water stress. Proc. Fla. State Hort. Soc. **79**:99–106.

Hilgeman, R. H., H. Tucker, and T. A. Hales. 1959. The effect of temperature, precipitation, blossom date and yield upon the enlargement of Valencia oranges. Proc. Amer. Soc. Hort. Sci. **74**:266–79.

Hilgeman, R. H., L. True and J. A. Dunlap. 1964. Effect of naphthaleneacetic acid spray and hand thinning on size of Kinnow mandarin fruit in Arizona. Proc. Fla. State Hort. Soc. **77**:84–87.

Hilgeman, R. H., W. L. Ehrler, C. E. Everling and F. O. Sharp. 1969. Apparent transpiration and internal water stress in Valencia oranges as affected by soil water, season and climate. *In:* Chapman, H. D. (ed.) Proc. First Intern. Citrus Symp. **3**:1713–24.

Holtzhausen, L. C. 1969. Observations on the developing fruit of *Citrus sinensis* cultivar Washington navel from anthesis to ripeness. Tech. Comm. No. 91, Dept. Agr. Tech. Serv. Gov't Printer, Pretoria, Republic of So. Africa.

Horanic, G. E., and F. E. Gardner. 1958. Effects of subfreezing temperatures on the viability of citrus seed. Proc. Fla. State Hort. Soc. **71**:79–81.

Idso, S. B., D. G. Baker, and D. M. Gates. 1966. The energy environment of plants. Advan. in Agron. **18**:171–219.

Iwamasa, M. 1969. Chromosome aberrations in citrus in relation to sterility and seedlessness. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. **1**:175–81. Univ. of Calif., Riverside, Calif.

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IWAMASA, M., and T. IWASAKI. 1963. On the sterility phenomenon caused by low temperatures in the Mexican lime (*Citrus aurantifolia* Swingle). Bul. Hort. Res. Sta. Japan, Ser. B, No. 2:25–45.

JAHN, O. L. 1970. Effects of maturity changes on nondestructive measurements of citrus fruit quality. U. S. Dept. Agr. Tech. Bul. No. 1410, 50 pp.

JONES, W. W., and C. B. CREE. 1965. Environmental factors related to fruiting of Washington navel oranges over a 38-year period. Proc. Amer. Soc. Hort. Sci. 86:267–71.

JONES, W. W., T. W. EMBLETON, and C. B. CREE. 1962. Temperature effects on acid, brix in Washington navel oranges. Calif. Citrog. 47:132–34.

JONES, W. W., T. W. EMBLETON, M. L. STEINACKER, and C. B. CREE. 1964. The effect of time of fruit harvest on fruiting and carbohydrate supply in the Valencia orange. Proc. Amer. Soc. Hort. Sci. 84: 152–57.

JONES, W. W., M. J. GARBER, and J. E. NEWMAN. 1966. A 30-year record of solar radiation. Univ. Calif. Agr. Expt. Sta. Leaflet 193.

KETCHIE, D. O. 1969. The effect of high temperature on citrus. *In:* Chapman, H. D. (Ed.) Proc. First Intern. Citrus Symp. 1:267–70. Univ. of Calif. Riverside, Calif.

KETCHIE, D. O., and A. L. BALLARD. 1968. Environments which cause heat injury to 'Valencia' oranges. Proc. Amer. Soc. Hort. Sci. 93:166–72.

KETCHIE, D. O., and J. R. FURR. 1968. Sunburn and heat injury of citrus. Calif. Citrog. 53:252, 270–73.

KOO, R. C. J. and A. A. MCCORNACK. 1965. Effects of irrigation and fertilization on production and quality of 'Dancy' tangerine. Proc. Fla. State Hort. Soc. 78:10–15.

KOZLOWSKI, T. T. 1968. Diurnal changes in diameters of fruits and tree stems of Montmorency cherry. Jour. Hort. Sci. 43:1–15.

KRAMER, P. J., and T. T. KOZLOWSKI. 1960. Physiology of trees. McGraw-Hill Book Co., New York. 642 pp.

KURIHARA, A. 1969. Fruit growth of satsuma orange under controlled condition. I. Effects of preharvest temperature on fruit growth, color development, and fruit quality in satsuma orange. Bul. Hort. Res. Sta. Japan, Ser. A, No. 8:15–30.

——— 1971. Fruit growth of satsuma orange under controlled condition. II. Effects of night temperature in the fall on fruit growth, color development, and fruit quality of satsuma orange. Bul. Hort. Res. Sta. Japan. Ser. A, No. 10:29–37.

LABANAUSKAS, C. K., D. R. RODNEY, W. REUTHER, and T. W. EMBLETON. 1958. Soil temperature effects on the vegetative growth, concentration and total absorption of minerals in citrus seedlings rootstock species. Ann. Rept., Proj. 193-C, 1958. Unpublished data on file at the Citrus Res. Center, Univ. of Calif., Riverside, Calif.

LANGRIDGE, J., and J. R. MCWILLIAM. 1967. Heat responses of higher plants. *In:* Rose, A. H. (ed.). Thermobiology. pp. 231–81. Academic Press. New York.

LEE, T. H., L. C. ERICKSON, and C. O. CHICHESTER. 1971. An evaluation of the use of grafted fruit for study of carotenoid and chlorophyll changes in regreening 'Valencia' orange peel. HortScience 6:231–32.

LENZ, F. 1969. Effect of day length and temperature on the vegetative and reproductive growth of Washington navel orange. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. 1:333–38. Univ. of Calif. Riverside, Calif.

LETEY, J. JR., L. H. STOLZY, and W. D. KEMPER. 1967. Soil aeration. *In:* Hagan, R. M., H. R. Haise, and T. W. Edminster (eds.) Irrigation of agricultural lands. pp. 941–49. Amer. Soc. Agron. Madison, Wis.

LIEBIG, G. F., and H. D. CHAPMAN. 1963. Effect of variable root temperature on the behavior of young navel orange trees in a greenhouse. Proc. Amer. Soc. Hort. Sci. 82:204–09.

LONG, W. G., and M. B. SUNDAY. 1962. Seasonal changes in Florida Murcott Honey oranges. U. S. Dept. Agr. Tech. Bul. No. 1271, 39 pp.

MCCARTY, C. D., W. D. KEMPER, and H. Z. HIELD. 1965. Mandarin, tangelo and tangor maturity studies—1963–64 season. Calif. Citrog. 50:122, 134–36, 138–39.

MARLOTH, R. H. 1949. Citrus growth studies. I. Periodicity of root-growth and top-growth in nursery seedlings and budlings. Jour. Hort. Sci. 25:50–59.

MAXIMOV, N. A. 1935. The plant in relation to water. A study of the physiological basis of drought resistance. 2nd imp. George Allen and Unwin, Ltd. London. 451 pp.

MENDEL, K. 1969. The influence of temperature and light on the vegetative development of citrus trees. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. 1:259–65. Univ. of Calif. Riverside, Calif.

MEREDITH, F. I., and R. H. YOUNG. 1969. Effect of temperature on pigment development in Red Blush grapefruit and Ruby blood oranges. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. 1: 271–76. Univ. of Calif. Riverside, Calif.

——— 1971. Changes in lycopene and carotene content of 'Redblush' grapefruit exposed to high temperatures. HortScience 6:233–34.

MINESSY, F. A., M. A. BARAKAT, and E. M. EL-AZAB. 1970. Effect of water table on mineral content, root and shoot growth, yield and fruit quality in 'Washington navel' orange and 'Balady' mandarin. Jour. Amer. Soc. Hort. Sci. 95:81–85.

MOONEY, H.A., and M. WEST. 1964. Photosynthetic acclimatization of plants of diverse origin. Amer. Jour. Bot. 5:825–27.

MONSELISE, S. P. 1951. Light distribution in citrus trees. Bul. Res. Counc. Israel. 1(3):36–53.

MONSELISE, S. P., and F. M. TURRELL. 1959. Tenderness, climate, and citrus fruit. Science 129:639–40.

MOSS, G. I. 1969. Influence of temperature and photoperiod on flower induction and inflorescence development in sweet orange (*Citrus sinensis* L. Osbeck), Jour. Hort. Sci. 44:311–20.

NAKAGAWA, Y. 1969. Studies on the favorable climatic environments for fruit culture. VI. Analysis of climatological condition in the major citrus production areas in the world. Bul. Hort. Res. Sta. Japan, Ser. A, No. 8:73–93.

NAUDE, C. J. 1958. The influence of rootstock and temperature on nutrient accumulation in citrus grown in solution culture. *In:* Tree physiology studies at UCLA, Special Rept. 1:104–24.

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NAUER, E. M. 1964. Photoresponses of citrus and other subtropical plants. Ann. Rept. Proj. H-1984. Unpublished data on file at the Citrus Res. Center, Univ. of Calif., Riverside, Calif.

NEWMAN, J. E. 1968. Estimating water needs of citrus orchards. Citrus Indus. **49**(1):19–24.

NEWMAN, J. E., W. C. COOPER, W. REUTHER, G. A. CAHOON, and A. PEYNADO. 1967. Orange fruit maturity and net heat accumulations. *In:* Shaw, R. H. (ed.). Ground level Climatology. pp. 127–47. Amer. Assoc. Adv. Sci. Publ. No. 86.

NII, N., K. HARADA, and K. KADOWAKI. 1970. Effects of temperature on the fruit growth and quality of satsuma oranges. Jour. Jap. Soc. Hort. Sci. **39**: 309–17.

ONGUN, A. R., and A. WALLACE. 1958*a*. Inorganic composition of small Washington navel orange trees on different rootstocks grown in a glasshouse with different root temperatures. *In:* Tree physiology studies at UCLA, Special Rept. **1**:75–83.

——— 1958*b*. Influence of root temperature on the growth of small Washington navel orange trees on three different rootstocks in a glasshouse. *In:* Tree physiology studies at UCLA, Special Rept. **1**:84–86.

——— 1958*c*. Transpiration rates of small Washington navel orange trees grown in a glasshouse with different rootstocks and at different root tempertures. *In:* Tree physiology studies at UCLA, Special Rept. **1**:87–103.

PATT, J., M. AHRONI, and J. BENOR. 1967. Time of differentiation of peel qualities in Shamouti orange. HortScience **2**:156–57.

PIRINGER, A. A., R. J. DOWNS, and H. A. BORTHWICK. 1961. Effects of photoperiod and kind of supplemental light on the growth of three species of citrus and *Poncirus trifoliata*. Proc. Amer. Soc. Hort. Sci. **77**:202–10.

POSSINGHAM, J. V., and P. E. KRIEDEMANN. 1969. Environmental effects on the formation and distribution of photosynthetic assimilates in citrus. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. **1**:325–38. Univ. of Calif. Riverside, Calif.

RASMUSSEN, G. K., A. PEYNADO, R. HILGEMAN, J. R. FURR, and G. CAHOON. 1966. The organic acid content of Valencia oranges from four locations in the United States. Proc. Amer. Soc. Hort. Sci. **89**:206–10.

REUTHER, W. 1969. Premature fruit drop. Mimeo report, 9 p. Univ. of the West Indies, St. Augustine, Trinidad.

——— 1972. Temperature effects on citrus fruit growth and development. Proc. 18th Intern. Hort. Cong. **4**:292–304.

REUTHER, W., T. W. EMBLETON, and W. W. JONES. 1958. Mineral nutrition of tree crops. Ann. Rev. Plant Physiol. **9**:175–206.

REUTHER, W., and E. M. NAUER. 1972. Project 2120: The influence of climatic factors on the growth and fruiting of citrus and other subtropical fruits. Unpublished data on file at Univ. Calif. Agr. Expt. Sta., Riverside, Calif.

REUTHER, W., G. K. RASMUSSEN, R. H. HILGEMAN, G. A. CAHOON, and W. C. COOPER. 1969. A comparison of maturation and composition of 'Valencia' oranges in some major subtropical zones of the United States. Jour. Amer. Soc. Hort. Sci. **94**:144–57.

REUTHER, W., and D. RIOS-CASTAÑO. 1969. Comparison of growth, maturation and composition of citrus fruits in subtropical California and tropical Colombia. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. **1**:277–300. Univ. of Calif. Riverside, Calif.

REUTHER, W., and P. F. SMITH. 1952. Relation of nitrogen, potassium and magnesium fertilization to some fruit qualities of Valencia oranges. Proc. Amer. Soc. Hort. Sci. **59**:1–12.

REUTHER, W., P. F. SMITH, G. K. SCUDDER, and G. HRNCIAR. 1957. Relation of timing and amount of nitrogen to orange yield, fruit quality and leaf composition. Proc. Amer. Soc. Hort. Sci. **70**:237–44.

RIOS-CASTAÑO, D., R. TORRES-M., and S. CAMACHO-B. 1968. Ensayo de patrones para las naranjas 'Indian River' y Valle Washington en Colombia. Agricultura Tropical **24**:491–96.

ROWE, R. N., and P. B. CATLIN. 1971. Differential sensitivity to waterlogging and cyanogenesis by peach, apricot, and plum roots. Jour. Amer. Soc. Hort. Sci. **96**:305–08.

ROY, W. R., and F. E. GARDNER. 1945. Seasonal absorption of nutrient ions by orange trees in sand culture. Proc. Fla. State Hort. Soc. **58**:25–36.

RYGG, G. L., and M. R. GETTY. 1955. Seasonal changes in Arizona and California grapefruit. U. S. Dept. Agr. Tech. Bul. 1130, 44 pp.

SAVAGE, Z. 1968. Thirty-five years of citrus costs and returns in Florida. Univ. Fla. Agr. Ext. Serv. Econ. Ser. 68–3. Gainesville, Fla. 22 pp.

SHULER, P. E., J. W. TODD, and E. F. SCARBOROUGH. 1971. Florida Agricultural Statistics. Citrus Summary 1971, Florida Dept. Agr., Tallahassee, Fla.

SMITH, P. F., and W. REUTHER. 1950. Seasonal changes in Valencia oranges trees. I. Changes in leaf dry weight, ash, and macro-nutrient elements. Proc. Amer. Soc. Hort. Sci. **55**:61–72.

SMITH, R. L., and A. WALLACE. 1956. Influence of cation ratio, temperature, and time on adsorption and absorption of calcium and potassium by citrus and other plant species. Soil Sci. **82**:9–18.

STEARNS, C. R., and G. T. YOUNG. 1942. The relation of climatic conditions to color development in citrus fruit. Proc. Fla. State Hort. Soc. **55**:59–61.

STEBBINS, G. L. 1969. The effect of asexual reproduction on higher plant genera with special reference to Citrus. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. **1**:455–58. Univ. of Calif. Riverside, Calif.

STUBBS, L. L. 1968. Apparent elimination of exocortis and yellowing viruses in lemon by heat therapy and shoot-tip propagation. *In:* Childs, J. F. L. (ed.). Proc. 4th Conf. Intern. Org. Citrus Virol. pp. 96–99. Univ. of Fla. Press, Gainsville, Fla.

TAYLOR, C. A., and J. R. FURR. 1937. Use of soil-moisture and fruit-growth records for checking irrigation practices in citrus orchards. U. S. Dept. Agr. Circ. 426:23 pp.

THOMPSON, C. R., L. H. STOLZY, and O. C. TAYLOR. 1965. Effects of soil suction, relative humidity and temperature on apparent photosynthesis and transpir-

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ation of rough lemon (*Citrus jambhiri*). Proc. Amer. Soc. Hort. Sci. **87**:168–75.

THOMPSON, C. R., O. C. TAYLOR, M. D. THOMAS, and J. O. IVIE. 1967. Effects of air pollutants on apparent photosynthesis and water use by citrus trees. Environmental Sci. Tech. **1**:644–50.

TORRES-M., R., and D. RIOS-CASTAÑO. 1968. Crecimiento y maduración de frutas cítricos en el Valle del Cauca. Agricultura Tropical **24**:502–17.

TUCKER, D. P. H., and W. REUTHER. 1967. Seasonal trends in composition of processed 'Valencia' and navel oranges from major climatic zones of California and Arizona. Proc. Amer. Soc. Hort. Sci. **90**:529–40.

TUKEY, L. D. 1956. Some effects of night temperatures on the growth of McIntosh apples, I. Proc. Amer. Soc. Hort. Sci. **68**:32–43.

——— 1959. Periodicity in growth of fruits of apples, peaches and sour cherries with some factors influencing this development. Pa. Agr. Expt. Sta. Bul. No. 661.

——— 1960. Some effects of night temperature on growth of McIntosh apples, II. Proc. Amer. Soc. Hort. Sci. **75**:39–46.

——— 1964. A linear electronic device for continuous measurement and recording of fruit enlargement and contraction. Proc. Amer. Soc. Hort. Sci. **84**: 653–60.

VAN BAVEL, C. H. M., J. E. NEWMAN, and R. H. HILGEMAN. 1967. Climate and estimated water use by an orange orchard. Agr. Meteorol. **4**:27–37.

VAN DER VEEN, R., and G. MEIJER. 1959. Light and plant growth. Cleaver-Hume Press, Ltd. London. 161 pp.

WALLACE, A. 1953. Nitrogen absorption and translocation by citrus cuttings at different root temperatures. Proc. Amer. Hort. Sci. **61**:89–94.

WANG, J. Y. 1967. Agricultural meteorology. Agriculture Weather Information Service, San Jose, Calif. 693 pp.

WEBBER, H. J. 1943. Plant characteristics and climatology. *In:* Webber, H. J. and L. D. Batchelor (eds.) The Citrus Industry, **1**:41–69. Univ. Calif. Press., Berkeley, Calif.

WEBBER, H. J., W. REUTHER, and H. W. LAWTON. 1967. History and development of the citrus industry. *In:* Reuther, W., H. J. Webber, and L. D. Batchelor (eds.). The Citrus Industry. **1**:1–39. Univ. Calif. Div. Agr. Sci., Berkeley, Calif.

WENT, F. W. 1953. The effect of temperature on plant growth. Ann. Rev. Plant Physiol. **4**:347–62.

——— 1957. The experimental control of plant growth. Chronica Botanica Co., Waltham, Mass. 343 pp.

YANG, H. J., and S. NAKAGAWA. 1970. Studies on the male sterility of Satsuma orange (*Citrus Unshiu* Marc.). Effect of temperature on the recovery of pollen fertility concerning the metabolism of carbohydrates and enzyme activities in anther. Jour. Jap. Soc. Hort. Sci. **39**:6–19. (In English.)

YOUNG, L. B., and L. C. ERICKSON. 1961. Influence of temperature on color change in Valencia oranges. Proc. Amer. Soc. Hort. Sci. **78**:197–200.

YOUNG, R., F. MEREDITH, and A. PURCELL. 1969. Redblush grapefruit quality as affected by controlled artificial climates. Jour. Amer. Soc. Hort. Sci. **94**: 672–74.

YOUNG, R. H. 1961. Influence of day length, light intensity, and temperature on growth, dormancy, and cold-hardiness of Red Blush grapefruit trees. Proc. Amer. Soc. Hort. Sci. **78**:174–80.

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CHAPTER 10

The Science and Technology of Frost Protection

F. M. TURRELL

PART I. FROST-PROTECTION TECHNOLOGY

Almost all of today's basic frost-protection methods have been used for the past half century, although recent years have seen many improvements in weather forecasting, frost-warning communication, and frost-protection equipment and techniques. Much new technical information about frosts has been acquired since the first edition of *The Citrus Industry,* however, and this has led to significant advances in both the theory and practice of frost protection.

This chapter incorporates such new data and information to provide an up-to-date treatise on orchard frost-protection technology (Part I) and a convenient reference for current information on the physics and physiology of freezes, frost damage, and frost-protection methods (Part II and Appendix III). Part I covers orchard frost-protection methods, the influence of orchard management practices on frost damage, the treatment of frost-damaged trees, weather damage to fruit, and relative cold hardiness of scion varieties and rootstocks. Part II of this chapter is concerned with heat transfer in citrus orchards, atmospheric and ground factors in freezes, and the physiology of freeze damage. Thus, Part I is addressed primarily to those concerned with application of frost-protection technology to orchard management, whereas Part II will prove most useful to those concerned with research and development in the field of frost-protection technology.

The California citrus industry and institutions serving it, both public and private, have been leading pioneers in developing scientific frost-protection techniques for citrus orchards. Very important contributions, especially in the last two decades, have been made also by the Texas and Florida citrus industries. Large-scale frost protection by heating or wind machines as an agricultural practice is largely confined to the citrus-growing industries of the United States. Some applications are made in citrus and deciduous fruit orchards in other parts of the world, but these are largely adaptations of techniques developed in California citrus culture. Thus, this chapter focuses heavily on California advances and practices in frost protection.

Information on global climatic conditions (including frosts and freezes) may be found in Chapter 2 of Volume I, which is titled "Commercial Citrus Regions of the World." Although many company and trade names are mentioned in this chapter, no recommendation of any commercial product is made or intended by either the author or the University of California.

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FROST AND FREEZES

Economic Implications of Frosts and Freezes

Despite conversion of many old citrus orchards to living space for an exploding population, citrus acreage has continued to expand in most of the world's citrus-producing countries over the past twenty years, with most of that expansion occurring in areas subject to damaging frosts and freezes. Technology for protecting new orchards as well as long-established groves has advanced, but the overall problem of frost protection remains. It still ranks in importance with problems associated with pest control, nutrition, and irrigation.

Freezes in December, 1962, and January, 1963, for example, caused severe damage and economic loss in almost all citrus-growing nations of the northern hemisphere. Florida reported a total loss of 50 million boxes of oranges, and an additional 50 million boxes of fruit had to be salvaged as concentrate. About 61 per cent of the fruit on trees at the time of the freeze were affected, and 7 to 10 million trees were killed. Although California, as a whole, suffered little damage, the Central Valley still had losses of around 40 per cent of the unpicked crop of 11 million boxes. Economic loss was estimated at $21 to $30 million, exclusive of the loss represented by the killing of nearly a half million young trees. Arizona lost 50 per cent of its crop of 1.25 million boxes by freezing. Effects of the 1963 freeze in the United States have been analyzed by a number of investigators (Anonymous, 1963*e;* Cooper, 1963*a;* Cooper, Hearn *et al.,* 1963*a;* and Simpson, 1963).

Elsewhere in the world's citrus-growing areas, Mexico reported freeze damage as far south as Vera Cruz, Spain suffered fruit loss of about 37 per cent, Italy experienced damage amounting to 66 per cent (Anonymous, 1963*b*), and some damage was reported from North Africa and Turkey. Japan escaped fruit damage because harvesting occurred prior to the freeze (but approximately 10 per cent of its younger trees were lost even though they were protected by rice straw wrappings and mats).

In the 1960–61 season, Texas produced around 6.8 million boxes of grapefruit and 3.5 million boxes of oranges from a total of about 75,000 bearing acres of citrus. A mid-January freeze in 1962 resulted in losses of 60 per cent (3.9 million boxes) of the Texas grapefruit crop and 50 per cent (1.7 million boxes) of the orange crop, so that production dropped to 2.9 million boxes of grapefruit and 1.8 million boxes of oranges for 1961–62. One-year-old to three-year-old trees, whose trunks had been banked with soil, were killed back to the levels of soil insulation, and 35 per cent of the four-year-old to six-year-old trees were killed. Of the nonbanked seven-year-old to ten-year-old trees, 10 per cent were killed, and 5 per cent of the eleven-year-old to fifteen-year-old trees perished (Rohrbaugh, 1962). Of the remaining citrus trees, only about half bore fruit in the 1962–63 season, and total production fell to about 70,000 boxes of grapefruit and 40,000 boxes of oranges. Another freeze in January, 1963, set Texas trees almost back to their level of growth in January, 1962. As a consequence, the 1963–64 yield was 500,000 boxes of grapefruit and 240,000 boxes of oranges (Shuler and Scarborough, 1964). All of this illustrates the effects that a series of freezes can have on a particular citrus-growing region. It wasn't until eight years later (1968–69) that recovery in Texas was sufficient for total citrus production to equal or exceed the level of the 1960–61 season (Shuler, Todd, and Scarborough, 1971).

Although periodic losses from disastrous freezes cannot be prevented, it can be said that without development of modern frost-protection techniques, the current (1971) U. S. citrus industry of around 1.2 million bearing acres producing 283 million boxes (Shuler *et al.,* 1971) would not be possible.

Frosts or Freezes?

Little uniformity exists in the usage of the terms "frost" and "freeze." Climatologists, meteorologists, citrus growers, news reporters, and the public frequently fail to differentiate between the two terms. For example, the terms as employed by Webber and Batchelor (1943) and Batchelor and Webber (1948) were nearly interchangeable, except that "freeze" usually indicated lower temperatures and more extensive plant damage.

Geiger (1965) used "killing frost" or "advective freeze" in connection with a massive wave of cold air arriving from polar regions, but in common California usage this movement of a large mass of cold air into an agricultural area is called a freeze. Geiger's term "radiation frost" referred to conditions that resulted in air, plant, and soil temperatures being lowered to the freezing point through loss of heat by radiation. In this case,

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California usage agrees with the employment of the term "frost."

To complicate the terminology, frosts are often differentiated further. A hoar frost or white frost, as an example, results when atmospheric moisture freezes in small crystals on solid surfaces, whereas in black frosts (or the European equivalent "brown" frost) little or no crystals occur due to the air in the lower level being too dry to form them. Formation of ice crystals is dependent upon dew point, which is the temperature to which air must cool for atmospheric moisture to condense—the drier the air, the lower the dew point. The black frost, with no moisture crystallization, is usually more dangerous than white frost because its temperatures are lower, although not low enough to condense moisture from relatively dry air. In black frosts, dew points are very low, and always lower than the soil and plant-surface temperatures, which, in turn, are colder than the ambient air. A more detailed discussion of the significance of the dew point is presented in Appendix III (p. 506).

One distinction made between frosts and freezes concerns wind velocity and thickness of the cold air mass. In an advective (wind) freeze, wind velocity exceeds 3 miles per hour at night near the ground surface, and thickness of the cold air mass ranges from 500 to 5,000 feet or more. For radiation frost conditions, wind velocity is less than 3 miles per hour, and thickness of the cold air mass varies from some 30 feet to 200 feet. There are also damaging freeze-frost combinations—periods of gusty, freezing winds interspersed with moments of frosty calm.

Although fine distinctions may not be adhered to throughout this chapter, "freeze" will usually be employed to refer to advective (windy) cold conditions, and "frost" will generally be used in reference to cold but calm conditions. Distinctions between the two terms can be very important to citrus growers faced with predictions of cold weather. Will it be a frost or freeze? The protective measures the grower decides to use can depend on the answer, since at present the most effective methods for coping with a frost or a freeze are significantly different. Next comes the question of what combined or compromise methods might be most effectively used in developing protective methods that take into account the somewhat erratic frequency of occurrence of the two types of damaging cold weather. Severely damaging freezes may occur at approximately ten-year intervals. At the same time, the greater

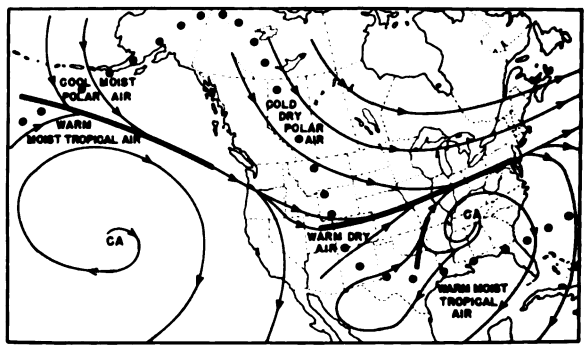

Fig. 10–1. Normal positions of centers of action and principal air currents for late fall and winter in the United States. Line of large dots shows location of abnormal jet stream during freeze of January, 1963. (After I. P. Krick, 1939; and Anonymous, 1963*b*; courtesy of U. S. Weather Bureau and Irving P. Krick Associates, Inc.)

frequency of frosts can mean that several frosts, although less damaging individually, will, in the aggregate, result in economic loss as great as from one severe freeze.

Frequency of Frost and Freezes

Another indication of the importance of frost protection to the citrus producers of the world is the magnitude and frequency of frosts and freezes throughout many of the most important citrus-growing regions. Although man is studying possible means for controlling the weather and has already made small modifications to microclimates, prospects still remain faint for significantly affecting the intensity and frequency of frosts and freezes. Today's citrus grower still must face most natural elements on their own terms. Arctic storms, through largely predictable, still loom as uncontrollable threats, as do the less blustery cold fronts with their potential of radiation frosts. Since weather poses an unrestrainable and constant menace, the grower can offset winter's onslaughts only by taking measures to minimize their effects.

In the northern hemisphere, the occasional advance of cold polar air into subtropical regions results in very low air temperatures, ranging from −13° C to −2° C (8° F to 28° F), which are damaging to tropical or subtropical plants, including citrus. The probability of occurrence is small prior to the winter solstice (December 21), but it increases greatly throughout January and gradually declines from mid-February until the spring solstice (March 21). Severe freeze-frost combinations do sometimes occur near the middle of Novem-

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ber—seldom after the middle of February—and milder frosts occur occasionally in March and April in citrus areas.

West of the Rocky Mountains in the United States, polar air masses swinging counterclockwise southward and eastward from the Aleutian Islands meet with tropical air masses, most frequently from central California northward, whereas east of the Rockies masses of cold air from central and northern Canada bring rain or snow to much of the country (fig. 10–1). Freezes (caused by massive inroads of cold air) occur in subtropical regions when a cold front of dense air underruns a warmer air mass and pushes into southern latitudes, as shown by the displacement of the jet stream southward (dotted line in fig. 10–1). The advance of cold fronts may be very rapid, accompanied by rain, sleet, or snow. Usu-

Table 10–1
AVERAGE INTERVALS BETWEEN FROSTS OR FREEZES OF VARIOUS TEMPERATURES DURING VARIOUS PERIODS AT SELECTED LOCATIONS IN CALIFORNIA, FLORIDA, AND TEXAS

Temperature and Location[a]	Observation Period	Interval Between Frosts or Freezes (Years)
29 to 25°F		
Indio, California	1907–1958	1.1
Riverside, California	1922–1958	1.1
Ocala-Wiersdale, Florida	1937–1958	1.0
Orlando, Florida	1937–1958	2.2
Avon Park, Florida	1937–1958	1.4
Crystal City, Texas	1931–1958	1.1
Weslaco, Texas	1925–1958	2.9
Brownsville, Texas	1894–1958	2.6
	Mean	1.7
25 to 22°F		
Indio, California	1907–1958	1.6
Riverside, California	1922–1958	3.1
Ocala-Wiersdale, Florida	1894–1958	2.5
Orlando, Florida	1894–1958	3.6
Avon Park, Florida	1894–1958	4.1
Crystal City, Texas	1931–1958	1.6
Weslaco, Texas	1925–1958	5.0
Brownsville, Texas	1894–1958	5.0
	Mean	3.3
22°F or lower		
Indio, California	1907–1958	3.2
Riverside, California	1894–1958	10.8
Ocala-Wiersdale, Florida	1894–1958	3.1
Orlando, Florida	1894–1958	8.0
Avon Park, Florida	1894–1958	10.8
Crystal City, Texas	1931–1958	2.7
Weslaco, Texas	1925–1958	11.7
Brownsville, Texas	1894–1958	13.0
	Mean	7.9

Source: Cooper and Peynado (1959).

[a] The locations were at the U. S. Date Field Station, Indio; University of California Citrus Research Center, Riverside; Climatological Station at Avon Park, 1894–1936, and at Fruit-Frost Station No. 3328, 4 miles NE of Avon Park, 1937–1958; Climatological Station at Orlando, 1894–1938, and at Fruit-Frost Station No. 2328B on Kiawassee Road, 1939–1958; Climatological Station at Ocala, 1894–1936, and Fruit-Frost Station No. 1724B near Wiersdale, 1937–1958; Climatological Station at Brownsville, 1894–1958; Texas Agricultural Experiment Station, Substation No. 15 at Weslaco; Texas Agricultural Experiment Station, Substation No. 19 at Crystal City.

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ally they are followed by rapid clearing, although dry cold air remains.

It is impractical to discuss in detail characteristics of the various types of winter storms that bring frosts and freezes to the widespread citrus regions of the world. To describe those storms affecting citrus regions of the United States—or even southern California only—would require far too much space in this chapter.

Although records of damaging cold temperatures in Florida go back as far as 1747 (Wilder, 1948), it is not possible to determine with certainty from these records whether the noted cold weather occurrences were calm air radiation frosts or freezes caused by massive inroads of cold air. Even from the study of Cooper and Peynado (1959) of the frequency of damaging cold-weather events in California, Texas, and Florida, it is difficult to make definite distinctions between frosts and freezes. The Cooper-Peynado study, based on records beginning in 1894, is summarized in table 10–1.

As shown in table 10–1, the relatively mild cold conditions with temperatures between 29° F and 25° F occurred on the average of every 1.7 years in the three principal citrus-growing areas. The California locations were subjected to these mildly cold temperatures every 1.1 years, whereas in Florida the interval ranged from 1.0 to 2.2 years, and in Texas from 1.1 to 2.9 years. The longer intervals in the moister Florida and Texas areas suggest that these minimum temperatures represent radiation frost. Minimum temperatures of 25° F or lower occurred on the average of every 3.3 years and 22° F or lower on the average of every 7.9 years. Again, the short time intervals in the 25° F or lower and in the 22° F or lower temperature ranges in drier areas such as Indio compared with Riverside, Ocala-Wiersdale compared with Orlando and Avon Park, Florida, and Crystal City compared with Weslaco and Brownsville, Texas, suggest that these temperatures are associated with radiation frosts. When temperatures were 22° F or lower in the moist areas of any region, it is probable the low temperatures were the result of a freeze. Such temperatures occurred at intervals of 10.8 to 13 years.

The graphic representation (figs. 10–2, 10–3, 10–4) of the history of the lowest recorded temperatures of freeze years for the eight citrus-growing areas covered in table 10–1 indicates rough cycles of cold and warm winters. This is most apparent in the lowest temperature data depicted for Indio, California.

It is evident from a close review of figures 10–2, 10–3, and 10–4 that such a history of frosts

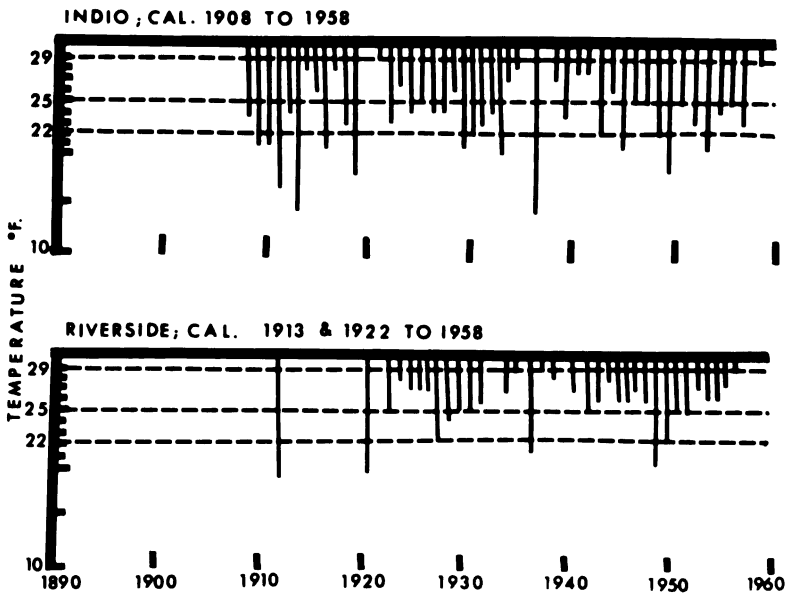

Fig. 10–2. Annual minimum air temperatures at selected locations in southern California for years when air temperatures dropped to 29° F or lower. The data for Indio are from the U. S. Date and Citrus Station, Indio, and those for Riverside are from the University of California Citrus Research Center. (After Cooper and Peynado, 1959.)

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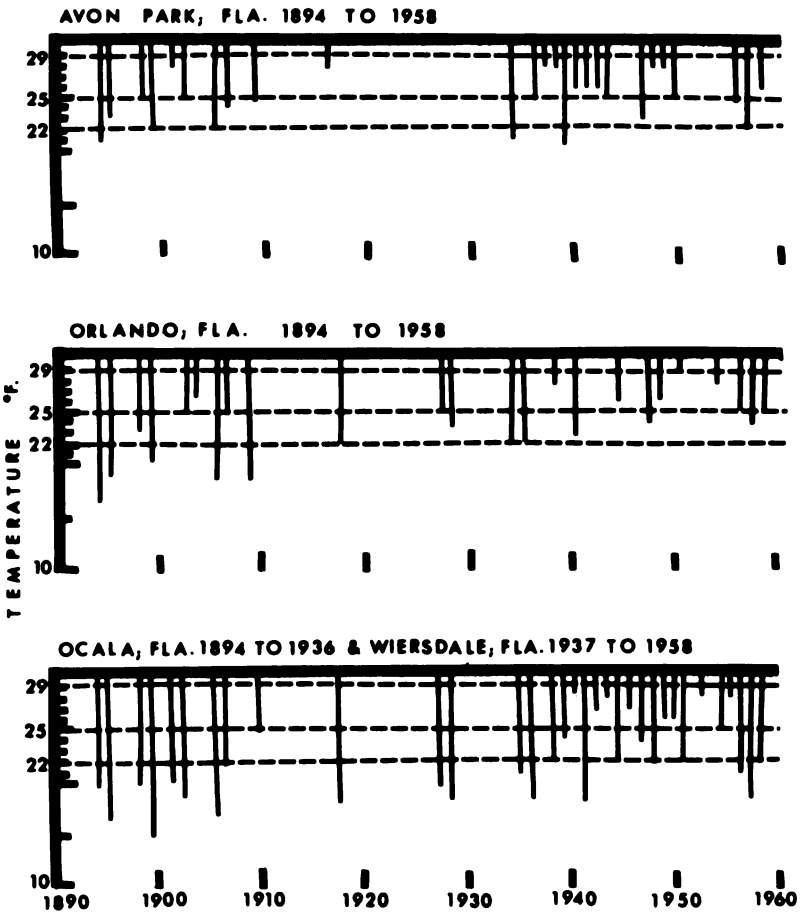

Fig. 10–3. Annual minimum air temperatures at selected locations in central Florida for those years when air temperatures dropped to 29° F or lower. Data from 1894 to 1936 are from U. S. Weather Bureau Climatological stations located in the respective towns, while the data from 1937 to 1958 are from Fruit-Frost Stations No. 3328 at Avon Park, No. 2328B at Orlando, and No. 1724B at Wiersdale. The records of minimum temperatures in the freezes of 1898 and 1899 are missing from Avon Park, but estimated minimums of 25° F and 22° F have been inserted. (After Cooper and Peynado, 1959.)

and freezes for any given area cannot be used for reliably predicting a warm or cold winter, a series of mild frosts, or a severe freeze. Cyclic patterns may be apparent, but so are breaks in those patterns. A "pairing" of the most severe frosts and freezes—two occurring in consecutive years—may at first appear to be a natural phenomenon, but then the history reveals exceptions. The most such a history offers the grower is a picture of weather probabilities that he can use for planning frost-protection measures and systems.

Variety of Protective Measures

The principal methods of frost protection involve using heaters to contribute heat to an orchard, using wind machines for distributing or redistributing heat in and above an orchard for most effective use by trees and fruit, and incorporating both heaters and wind machines into a protective system. The many types of heaters and varieties of fuels present the grower with a wide choice for his particular circumstances, and the wind machines too offer diversity in characteristics and performance.

Many other methods or means of lesser importance to be considered by growers either in establishing an orchard or in managing one involve utilizing certain natural features of an area as well as employing manufactured items. For instance, the grower may locate his orchard near

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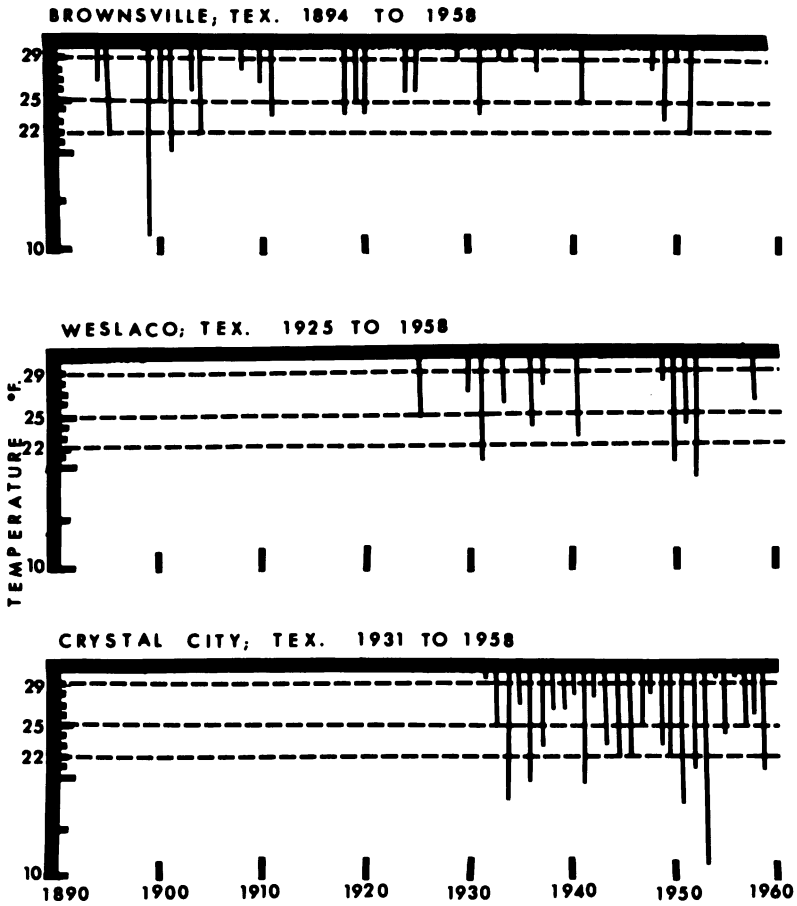

Fig. 10–4. Annual minimum air temperatures at selected locations in south Texas, for those years when air temperatures dropped to 29° F or lower. Data for Brownsville is from the U. S. Weather Bureau station; that for Weslaco is from the Texas Agricultural Experiment Station, Substation No. 15; and that for Crystal City is from the Texas Agricultural Experiment Station, Substation No. 19. (After Cooper and Peynado, 1959.)

an existing natural windbreak, plant trees for a windbreak, or erect a man-made windbreak. The grower may choose a plot because of its proximity to a body of water, or he may use water from wells to warm his orchard during a cold wave. Both natural and man-made insulation materials are at the disposal of most growers.

The grower may also modify an existing natural feature. He may, for example, open up a natural cold air dam at the lower portion of his orchard. Examples of other options open to growers are the planting of cover crops in an orchard, and, conversely, the removal of all vegetation from a stand of citrus. The options, major and minor, are so numerous and weather conditions so variable that every grower at times must wish for a computer to help solve his frost-protection problems.

What a grower decides to do about frost protection usually depends on some prior knowledge of the cold weather expected in his grove. In many countries, one would have to make a conscious effort to avoid learning about tonight's or tomorrow's weather. Weather forecasts appear daily in newspapers and are broadcast constantly by radio and television stations. Forecasts are modified hourly as current information is received from weather stations strategically placed the world over.

In many countries, too, citrus growers receive special forecasts during the frost-freeze season predicting temperatures for pinpointed loca-

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tions. In California, for instance, the U. S. Weather Bureau's Fruit Frost Service broadcasts predictions of low-temperature readings for precise locations in the many citrus-growing areas of the state. These broadcasts are supplemented by tape recordings that repeat the weather information over a telephonic network covering all citrus districts. Similar services cover the citrus regions of Florida and Texas and other U. S. areas devoted to intensive production of crops subject to damage by cold.

Weather forecasting has been greatly refined in recent years. One of the most recent advances in weather forecasting technology came with the use of radiosonde and rawinsonde soundings of the upper atmosphere for dew point, pressure, temperature, and wind speed and direction. Such data has led to greater precision in determining the outlines and paths of weather fronts. The other advances are too numerous for detailing here.

Frost-protection computer programs, although perhaps technically possible at this writing, are not yet economically feasible for predicting the exact nightly temperature conditions in individual orchards and then stating precisely which measures should be taken to counteract them. Until such programs are available, the grower has to make his own decisions based on the latest weather reports and knowledge of his particular orchard and frost-protection equipment. He must weigh the cost of protecting his citrus crop against the possible cost of losing that crop, and losing leaves, buds, and trees either in part or in whole. Without the aid of a computer, he must decide for himself what course of action to take and which options to select in making both short- and long-range plans for frost protection. Most of the options—the many methods of frost protection—are discussed in the next two sections.

HISTORY OF FROST PROTECTION AND FORECASTING

Frost protection may be classified under (1) use of natural elements, and (2) use of artificial or man-made elements. As early as 1900, the influence of natural elements, such as air, ground, and plants, on frost protection were elucidated by McAdie (1901); only the details remained to be worked out. Strange as it may seem, frost forecasting was already in vogue in southern California before this time. The natural elements involved in frost protection will be dealt with in subsequent sections, so that it is not necessary to review early ideas on the subject here. Readers interested in the subject may also consult such early papers as those published by McAdie (1901), Humphreys (1914), Carpenter (1914), and Garthwaite (1914). The history of man-made elements and frost-warning systems is briefly presented in this section.

Combustion and Other Heating Methods

Crude smudging (use of smoky fires) for frost protection has an ancient history and has been carried out for hundreds of years in parts of Europe (Coit, 1915). The first use of frost-protection devices in southern California is attributed to the Wright brothers of Riverside, who began burning crude oil in iron pots and lard pails in 1888. A severe frost in 1896 initiated many frost-protection experiments, which were further pursued during the dry and frosty winters of 1897, 1898, and 1899. Similar experimentation was carried out simultaneously in Florida, where for many years wood fires were the primary means for supplying orchard heat (Hume, 1907, 1957). In 1896, Copely of Riverside first used coal baskets, and by 1900 the Limoneira Ranch in Ventura County had 112 baskets per acre.

The Wright brothers also piped steam through a Riverside orchard, using a 35-hp boiler connected to a 2-inch diameter central pipe which branched out in ¾-inch pipes every 40 feet. Similarly, E. A. Meacham of Riverside used a 12-hp boiler to heat water to 80° F. Sprinklers 50 feet above the ground were successfully used by A. J. Everett at Riverside, but sprinkling eventually proved unsatisfactory for California because the normally dry air caused too much cooling by evaporation. Everett also successfully used a lath house and canvas and muslin cloth coverings above the trees. As many as five acres were covered with tobacco cloth in each of two groves in Pomona and Corona. A lath house was successfully tried at San Fernando and a glass house at Fillmore (Carpenter, 1914). Windbreaks of trees were used by N. W. Blanchard in 1934, and P. Hall produced smudge for 10 acres by mounting a wet-straw burner on a sled and having it pulled around his orchard.

Irrigation was regarded by McAdie (1901) as the best method for frost protection. Carpenter (1914) emphasized the importance of cold air

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drainage on 14° F to 18° F inversions for frost protection, the advantages of certain hillside exposures, the meteorology of freeze conditions, and the serious problem of drying winds to which 50 per cent of the damage in the 1913 freeze was attributed.

Both the Leffingwell and the Limoneira Ranches (Ventura County) used coal heaters, but Teague (1944) during the 1913 freeze showed that the crude-oil orchard heater was the most efficient and economical means for frost protection. There were about one million smudge pots in California at this time. By 1938 there were some four million orchard heaters protecting 92,000 acres of citrus in California.

Orchard heaters were continually improved after the first use of oil in "lard pails." The stub-stack, baby cone, double-stack, lazy flame, Kittle, and Fugit heaters were among those developed. In 1951, the return-stack heater came to the fore as a nearly smokeless and highly efficient oil burner. Since the 1962 Texas and Florida freezes, solid-fuel heaters have received considerable renewed attention (Gerber, 1966; Hensz, 1969; Miller, Turrell, and Austin, 1966) with wax "candles," carbon briquettes, and petroleum-coke bricks predominating.

Wind Machines

Invention of the wind machine has been attributed to plant physiologist Stephen Hales (1677–1761), Curate of Teddington in Middlesex, England. He designed his wind machine to move odoriferous air from ships (Steward, 1965). The eminent meteorological physicist W. J. Humphreys (1914) suggested that mixing air artificially would make an excellent frost-protection method, but this he thought to be impossible. It was not until 1916 that E. S. Cobb built and installed at Lindsay, California, the first wind machine for mixing air to give frost protection of citrus (Hamilton, 1955). In 1919, Warren Towt helped build an improved model of Cobb's machine (Anonymous, 1919), and credited the saving of a navel orange crop to the wind machine (Towt, 1922).

The first wind machines were powered by automobile engines, and their propeller shafts were horizontal to the ground. L. J. Whitlock, however, tried a vertical shaft. On top of a 25-foot tower he mounted a large four-bladed fan on a vertical shaft, and met with such success that $30,000 was pledged for research on his "Weather Moderator" (Anonymous, 1922*b*), a low-power

Fig. 10–5. Forerunner of the Therm Retain wind machine with low-power gasoline engine at left. (Photo by F. D. Young 1924.)

version of which is shown in figure 10–5. This machine was the forerunner of the Therm Retain (pl. I, *A*, p. 380). John Allegro of Alhambra, California, went mobile. He mounted wind machines onto rubber-tired vehicles and had them pulled in trains around the orchard (Anonymous, 1922*c*).

Citrus growers quickly realized the wind machine's potential for California, and in May, 1922, the town of Covina featured a Frostless Convention at which several different types of wind machines were exhibited (see page of pictures, Anonymous. 1922*a*). Acceptance of the wind machine was not unanimous; for instance, Ford A. Carpenter, the U. S. Weather Bureau observer and meteorologist in Los Angeles, expressed doubt as to the effectiveness of the wind machine (Nutt, 1959), particularly during serious freezes accompanied by strong winds (Anonymous, 1922*c*). Many early investigations of windmachine effectiveness concerned use of the machine alone or with an attached heat source, and by 1924 numerous tests had been made (Anonymous, 1924).

Sam V. Wight started the employment of electric motors instead of gasoline engines, and in 1930 began experimenting with propellers, finally concluding that wind machine propellers

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should be designed differently from airplane propellers. Wight also recommended that wind machines be started early in the evening and run late in the morning and that when temperatures were very low, border heating be used in conjunction with the wind machines (Wight, 1939). The University of California, Davis, and the California Institute of Technology also experimented with propellers; they cooperated with propeller manufacturers in a five-year study of propeller design and performance (Grable, 1939).

The advective freeze of January, 1937, was a setback to wind machine adherents. Whitlock's Weather Moderator, Towt's Automatic Frost Protector, Wight's Orchard Protector, and Woodward's Frost Dispeller were successful in protecting trees on low ground (behind hills), but appeared to be of doubtful value on high ground or hilltops. J. C. Johnston, on the other hand, for the three-year period from 1933–34 through 1937–38, showed greater yields of Valencia oranges under wind-machine protection than with other methods (Johnston, 1939*b*). Some appraisals of wind machines were made by Young (1924), Johnston (1939*a*), Moses (1938), and Thompson (1937).

Between 1937 and 1950 much progress was made in the development and the effective use of wind machines, which was discussed at a forum on the freeze of 1949 (Nixon, 1949). In 1952, the University of California reported results of a thorough study on the successful operation of wind machines and recommended heater support (Adams, 1952). Also in 1952, a conference of 225 citrus growers convened in Santa Ana for reports on the use of the wind machines in Orange County, California, with largely favorable results being reported (Anonymous, 1952). The greatest single advance in wind machine technology of the 1950's came with the introduction of the "big fan" by National Frost Protection Company. The big fan's blade was 15¼ feet across and at 590 rpm delivered 1,100 pounds of thrust.

Over the years, wind machine design was changed considerably. The propellers or fans have evolved from airplane propellers of wood to aluminum ones designed specifically for mixing orchard air. Electric motors and diesel and butane engines have joined the gasoline engines for supplying power. Wind machine starters have developed from hand cranks to push-button starters to thermostatically-controlled devices. Some of these and other developments in wind machine technology can be seen in plate I, *A* (p. 380) and figures 10–6 through 10–10.

Fig. 10–6. Early wind machine with accessory heat from a furnace delivered over the edge of the cone. Powered by a 120-hp engine and fitted with standard airplane propeller. (Photo courtesy of R. W. Durrenburger.)

Fig. 10–7. An early wind machine, gasoline-engine powered, on a windmill tower. (Photo courtesy of National Frost Protection Co., Inc.)

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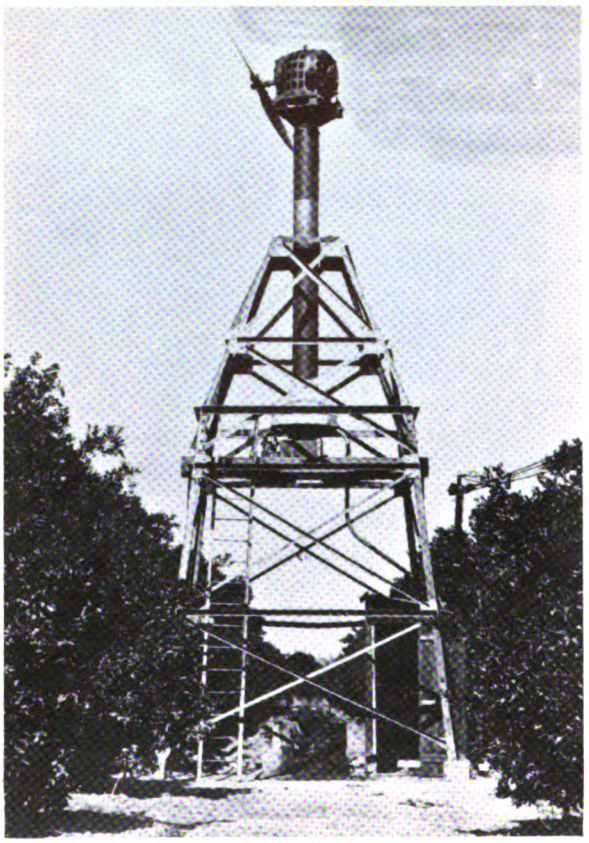

Fig. 10–8. Old electric wind machine mounted on windmill tower located near Lindsay, California. (Photo courtesy of Roy Simpson, U. S. Fruit Frost Service, Pomona, California.)

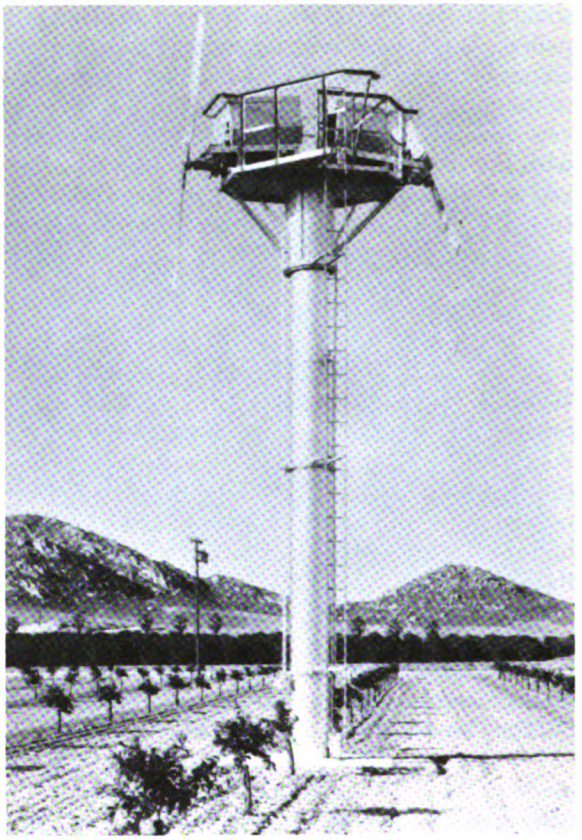

Fig. 10–9. Dual wind machine with dual gasoline engines, tower-mounted, with 14-foot flat-bladed aluminum propellers. Propellers are depressed 3° to 7° from horizontal depending on size of trees. (Photo courtesy of National Frost Protection Co., Inc.)

The historical growth of wind machine usage may be briefly summarized as follows. The first wind machine was patented in 1916 (Hamilton, 1955), and one was installed in Tulare County about that time. There were 70 machines in Tulare County in 1937 (Thompson, 1937) and 75 by 1939 (Johnston, 1939*a*). By 1938 there were 150 wind machines in California (Adams, 1952), and by 1950 there were 2,779 (1,561 gasoline, 1,018 electric, and 200 diesel). In 1952, it was estimated that the wind machine population of California had grown to 4,000 (Anonymous, 1952). By 1965 the 75 wind machines in Tulare County had increased to 1,634 (Optiz, 1965), and over 7,000 were to be found in the states of California and Arizona. Currently (1972), it is estimated that there are more than 10,000 wind machines in California and Arizona, and perhaps more than 1,000 in Florida.

Adoption of the wind machine in Florida and Texas has been slower than in California. By 1963 there were only 1,000 or so wind machines in these two states (Anonymous, 1963*c*). Three factors appear responsible: 1) relative flatness of terrain greatly diminishes the number of cold air lakes; (2) freezing weather or freezing microclimates develop only with an invasion of rapidly moving arctic air and macroclimate change; and 3) the higher prevailing relative humidities of Florida and Texas make alternative methods of frost protection, such as sprinkling, feasible when radiation frosts develop.

Frost-Warning Systems

The history of weather forecasting in California dates back to 1891. Alexander McAdie initiated weather forecasts as part of a program in which the newly-formed California Weather

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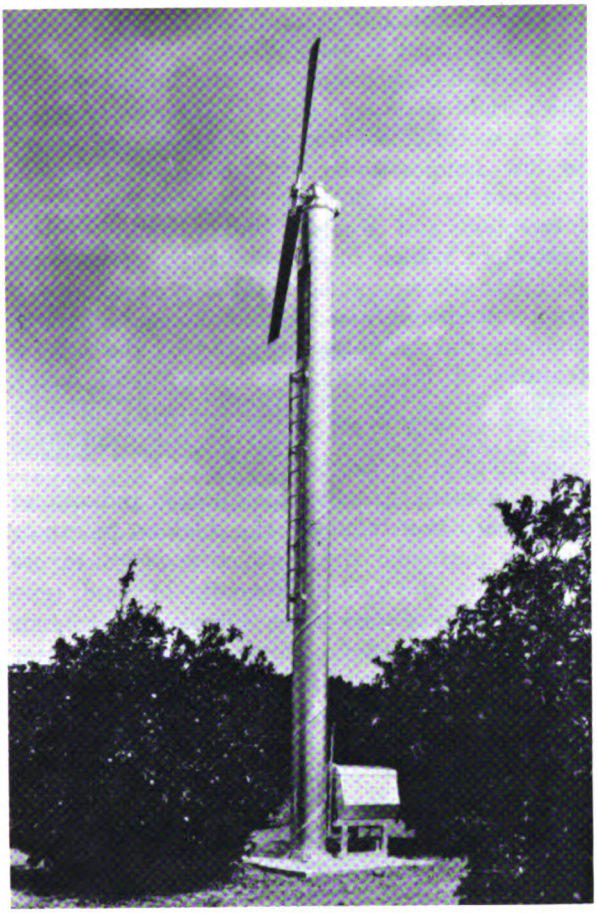

Fig. 10–10. Modern wind machine with engine at base. (Photo courtesy of National Frost Protection Co., Inc.)

Service (of the U. S. Weather Bureau under the Department of Agriculture) published weather and crop bulletins. California weather records go back even farther—at least to 1848, when the Army Medical Service began recording data. From 1850 to 1875, Dr. R. M. Logan compiled weather information about the San Francisco and Sacramento areas, and during the 1870's the Southern Pacific Railroad kept temperature records at many of its stations.

Citrus growers of the Riverside Horticultural Club first organized a cooperative effort with the U. S. Weather Bureau in 1896. Key low-temperature stations were equipped with frost alarms, and frost warnings were telephoned to all participating growers. In 1910, the Pomona Valley Orchard Protective Association was organized. The association employed six motorcycle riders to check 140 thermometer stations. Also in 1910, the Ontario Frost Protective League was established, to be followed in 1913 by the Tustin Frost Protective League.

Around 1917, the private frost-warning organizations of California were either dissolved or incorporated into the newly-established U. S. Weather Bureau's Fruit Frost Service, headquartered at Pomona. The Fruit Frost Service was extended to Redlands and Corona in 1921, to Upland, Azusa, Whittier, Santa Paula, and Lindsay in 1922, to the Imperial and Sacramento Valleys in 1930, to San Diego in 1939 (Durrenberger, 1956), to Orange County (Whittier District) in 1922, to Yuma Mesa in 1937, and to the Salt River Valley District in 1955 (Simpson, 1964).

In 1924, the frost warnings that had been transmitted by telephone (also by postcard around 1913) in southern California began to be broadcast by radio from Los Angeles and then in 1930 from Pomona via Los Angeles. For many years—into the 1950's—the name of the announcer, Floyd Young, was nearly synonymous with the U. S. Weather Bureau's Fruit Frost Service. The Fruit Frost Service is now administered by the U. S. National Oceanic and Atmospheric Administration. Currently, warnings broadcast from several radio and television stations are also tape-recorded and played back automatically when special telephone numbers are dialed. The main forecast by Dale Harris is at 7 P.M. over Station KFI, and is broadcast from the University of California, Riverside.

SOME BASIC CONSIDERATIONS

Elements of Heat Transfer

All frost-protection measures and systems are designed either to prevent the loss of heat from orchards or to replace heat that is lost. Four processes of heat transfer and conversion are involved: conduction, convection, radiation, and vaporization-condensation.

In conduction, heat is lost, gained, or distributed by molecular activity, the "warmer" molecules passing some of their energy to neighboring molecules, which, in turn, transfer some of the energy gained to the molecules next in line. Thus is heat or molecular energy conducted internally from a hot or warm area to the cooler or less active area of a given mass.

Convection is the principle way that heat is transferred through liquids and gases, both of which are poor heat conductors. In the process of convection, the heated fluid (liquid or gas) expands and rises and is replaced by cooler, denser

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fluid. Water in a kettle over a flame is heated throughout, largely by convection, as is the air in a room containing a stove.

Advection, though perhaps not considered a basic form of heat transfer, strongly resembles convection in effects. Advection is the horizontal movement of air that causes changes in temperature by bringing hot or cold air into an area or by mixing layers of air at different temperatures. Two examples of advection are the natural phenomenon of a wind-driven mass of polar air causing an advective freeze, and the man-made wind machine mixing of warm air with cold to keep orchard temperatures above the danger point.

The transfer of heat by radiation involves the conversion of internal energy into radiant form and the reversion of radiant energy into internal energy as the radiation from one body is absorbed by another. In a continuous process, all bodies, hot and cold, radiate energy, and all bodies receive radiation from others. The radiation emitted by a body takes the form of waves in space with a wide range of wavelengths. The short waves are perceived as light (0.3μ to 0.7μ) and the longer ones as heat (2.5μ to 25μ). The radiation from a fluorescent lamp is rich in short waves (light) and poor in long waves (heat), while the reverse is true of a glowing bed of hot coals.

Vaporization is the conversion of a substance to its vapor phase in a process involving heat. Although vaporization includes evaporation, boiling, and sublimation, the particular type of conversion most relevant to this chapter is evaporation (and the related phenomenon of transpiration). As evaporation uses up heat (and thus cools the substance evaporating), the reverse process of condensation—the conversion of a vapor to a liquid or solid state—produces heat. More detailed discussion of the physics of heat transfer—especially as it pertains to citrus plants and orchards—is found in Part II, beginning on page 408.

Heat transfer on a very large scale is evident in the weather. Indeed, the weather can be considered a vast functioning of heat transfer in all forms. The far reaches of the earth's surfaces are involved in heat transfer and the formation of weather. Conditions of the atmosphere react with conditions on the ground to influence weather. Heat transfer between sky and ground is continuous, and citrus groves in winter are greatly affected by this activity. For a detailed discussion of atmospheric and ground factors in frosts and freezes see Part II, page 408.

Well-nigh infinite are the interactions of the variables affecting heat transfer in orchards of the worldwide citrus-growing regions subject to low temperatures. Fortunately, the grower does not have to take into consideration *all* the interactions and variables when planning a frost-protection system for his orchard or when preparing to take immediate measures to prevent loss from a predicted frost. He does, however, have to consider the variables presented by the natural features of his particular orchard and weigh against those the counterbalancing variables offered by the many kinds of frost-protection equipment at his disposal.

Some of the natural features in and around an orchard that influence the decision to use or not use particular frost-protection measures are topography, the normal flowpaths of wind, type of soil, chemical state of the soil, moisture content of soil and atmosphere, temperature of the water available for irrigation or sprinkling, temperature of the ground, presence (or absence) of cover crops and windbreaks, dormancy status of the trees, probability of an atmospheric inversion layer, and proximity of bodies of water and other citrus orchards. All these factors are discussed in greater detail in subsequent sections.

Weather Factors

Advection, Radiation, and Topography.—It is necessary to have a basic conception of how the contrasting meteorological conditions associated with the two major freezing situations relate to topography to understand the use of either

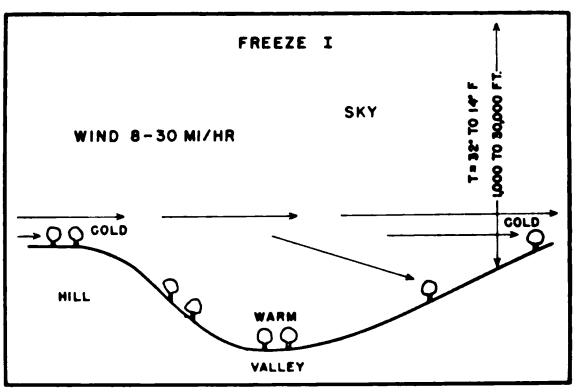

Fig. 10–11. Diagram showing the micrometeorology of a freeze in hilly country. In flat country, micrometeorology is similar to hilltop on left.

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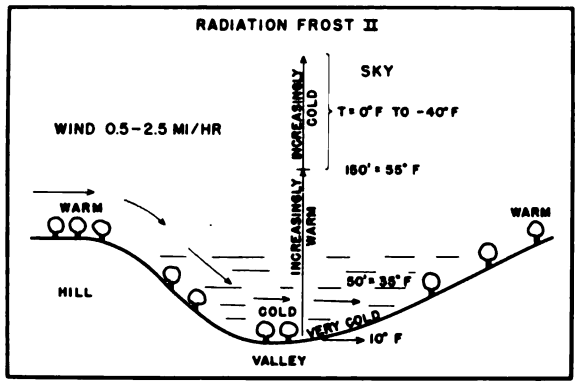

Fig. 10–12. Diagram showing the micrometeorology of a radiation frost in hilly country. A radiation frost may develop alone or as the second stage (calm) of an advection freeze. In the latter case, the hilltop trees enter the second stage very cold while the valley trees enter the calm night somewhat warmer.

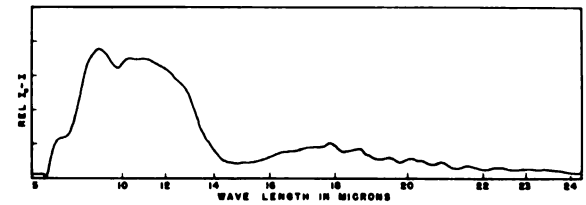

Fig. 10–13. Relative intensity ($I_o - I/I_o$) of the net radiation from earth's surface to space. (Relative intensity of net radiation where I_o = radiation from ground; I = back radiation from sky; $I_o - I$ = net radiation to sky.) (From Adel, 1958.)

wind machines or orchard heaters to reduce or prevent cold damage. The "advection freeze" or "wind freeze" developed with wind in either daylight or darkness and the "radiation frost," only developed without wind and in darkness, are aerodynamically different.

The advection freeze stratifies the air horizontally so that hilltops are cold and valleys warm (fig. 10–11). The radiation frost stratifies it vertically so that the air next to the ground (in the valley) is coldest and gradually becomes warmer with increased height (fig. 10–12). Usually air-flow of four to six miles per hour in the "superior stratum," 25 to 50 feet (or a minimum of 10 feet above tree tops) results in sufficient turbulence to mix the warm air of the "superior stratum" with cold air in the "inferior stratum," 0 to 25 feet, and radiation frosts do not develop. Frequently, in southern California at 6 P.M. a calm with very low air temperatures at five feet will indicate a severe radiation frost is developing, but at 10 P.M. a 2.5 mile per hour wind at the 25-foot level will serve to dispel it. This is the general situation in hilly, mountainous southern California. This situation is much less general in Florida and lacking in Texas.

Clouds and Fogs.—Terrestrial radiation has wavelength limits from 4μ to 120μ; the results of the most recent study are shown in figure 10–13. The warming effects of clouds on terrestrial temperatures has long been known. A cloud or dense fog of 50 meters thickness will absorb most outgoing infrared radiation, and, of course, the cloud will radiate as a black body. A severe frost may be predicted, but if clouds arrive no frost is usually expected to develop (De Boer, 1965). However, on occasion, local areas are frost damaged through the very clear openings that sometimes occur between clouds (for example, the Hemet and Temecula areas of California in December, 1967).

Through the radiation laws of Kirchoff, Wien, Stefan-Boltzman, and Beer, it is now clear that the principal radiation at terrestrial temperatures occurring on frosty nights in subtropical citrus areas is approximately that having a wavelength of 10μ. Clouds having water droplets 10μ to 25μ in diameter are excellent absorbers for those wavelengths, and a cloud of only about 150-foot thickness is required to absorb all terrestial radiation (Berry, Bollay, and Beers, 1945).

It was observed by Turrell and Austin (1960*b*) during the severe mid-November freeze in 1958 that groves which were suffering for water were badly frozen, whereas those which were irrigated the previous day or irrigated during the freezing night sustained little or no injury, particularly if a large wind machine also had been used. It was clear that sufficient water vapor could not be produced to add humidity to the upper atmosphere. Subsequently, (Turrell, Austin, and Perry, 1961) carried out experiments to determine how water prevented freeze damage. The irrigation water which had a temperature of 70° F first carried heat into the ground, then carried heat into the air above the grove. The interaction of the warm-water vapor from the irrigation water and cold air formed a fog in the orchard which was held among the trees. The absorption of longwave thermal radiation by fogs is very good. It seems probable that infrared radiation (6.25μ to 16.75μ) from the irrigation water and from the soil below was absorbed ("half-absorbed") in a

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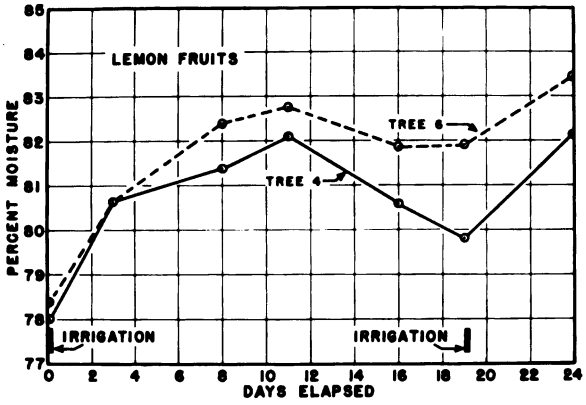

Fig. 10–14. The length of time required to hydrate lemons by irrigation. (After Furr and Taylor, 1939.)

3- to 7-foot thickness of fog (according to figures given by Falckenberg) held between citrus trees, while the entire terrestrial infrared spectrum was absorbed in less than a 100-foot layer (Geiger, 1965). The amount of heat that is trapped by the water vapor, of course, depends on its concentration and state. A fog, i.e., a cloud at ground level, having 71 to 100 per cent relative humidity at 4° F or less is more effective than a haze in which the atmosphere has a relative humidity of 70 per cent and a greater than 4° F difference in dew point (Stern, 1962). Examination of the relation between the temperature of the dew point and the per cent relative humidity at different freezing temperatures (shown in Part II, fig. 10–53, page 413) makes it clear that addition of extra heat to the orchard increases the amount of water vapor which orchard air can accommodate and adds significantly to the holding of heat in the orchard.

Moisture Status of the Plant

Although the literature is full of references indicating that dry seeds, spores, deciduous trees, etc., withstand very low temperatures without freeze damage, most nurserymen know that many plants suffering dryness will not show normal frost resistance. Numerous observations have been made indicating that desiccation increases loss from frost damage (Carpenter, 1914; Wilder, 1948; Levitt, 1956; Turrell and Austin, 1960*b*; Turrell, Austin, and Perry, 1960*a*, 1960*b*; and Vasilyev, 1961). After a citrus tree has become dehydrated, about ten days are required for the tree to become fully rehydrated (Furr and Taylor, 1939). The hydration curves of lemon fruit on two trees at Pomona, California are shown in figure 10–14. At the same time it should be realized that in certain citrus areas such as Texas, the trees can often only be brought to a dormant state by withholding irrigation water; and this will have a cold-hardening effect (Levitt, 1956; Cooper, 1959).

Heating Requirements

There are many variables that may affect the damage which frosts and freezes cause. These include meteorological, crop, and soil factors, among others. It is impossible at the present to put all of these, both qualitative and quantitative, into a mathematical equation and arrive at an exact answer for the heat requirement for protection against a particular frost or freeze in a given orchard situation. In time, this may be accomplished. It can be envisioned that the readout of the several instruments involved will be integrated on a single dial calibrated in British thermal units (BTU). However, some of the internal crop-tissue factors affecting susceptibility to frost damage may still have to be estimated qualitatively.

Sometime between 1913 and 1936, experienced citrus growers calculated, for example, that 50 heaters per acre, each heater burning 1 gallon of oil an hour and yielding 140,000 BTU (Adams, 1952), would give a total of 7,000,000 BTU per acre per hour. This figure does indeed come close to the kind of estimate needed for maximum heating requirements for orange orchards in the 1937 California freeze (Anonymous, 1937). Recent developments have made it possible to arrive at a practical estimate of the amount of heat required. If the temperature of an acre of trees of a given age drops 1° F or 10° F below freezing, we can now say what the amount of heat required to raise it back to 32° F will be. But many variables enter into the somewhat complex calculation of the estimated total heat required to protect a given citrus orchard in a specific freezing situation. Details of these variables and calculations are presented in Appendix III, p. 505.

For purposes of practical frost protection, it can be stated that between somewhat less than 1 to 2 million BTU's per acre per hour are lost during a radiation freeze damaging to citrus. Because of low efficiency, somewhere in the range of 3 to 6 million BTU's per acre per hour are required for protection with heaters, depending on wind speed and many other factors, including the climatic parameters of a particular citrus region. Modern, well-designed, oil-burning heaters

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produce from about 70,000 to 140,000 BTU's per hour (see table 10–4, p. 364), under average performance conditions, of which from about 10 to 30 per cent will be in the form of radiant heat (see table 10–5, p. 366). During advection or wind freezes, it is usually not possible to maintain air temperatures in heated areas much above those of unheated areas, and the radiant heat produced is the only protection afforded by heaters. Thus during wind freezes, the total amount of heat generated by heaters may need to be considerably in excess of the BTU's required for radiation freezes, perhaps as high as nine or ten million BTU's under extreme conditions.

PRINCIPAL FROST-PROTECTION METHODS

There are as many ways to heat citrus orchards as there are to heat habitations. Wood, coal, oil, natural and processed gases, and electricity, as well as a wide variety of natural and artificial insulating materials have been used around the world in protecting vegetation from frost. Water too can be used to supply heat to an orchard. Experiments with foams and artificial fogs for frost protection have produced promising results for some types of vegetation in certain parts of the world. Wind machines alone, or in conjunction with heaters, protect by mixing warmer air from upper inversion stratas with colder air of the lower ground strata. Recently, experiments have been conducted with the use of helicopters for mixing inversion air with ground air (Anonymous, 1971*b;* Small, 1949).

Wind Machines

Although used as long ago as 1916, wind machines can be considered a comparatively recent development as far as extensive use goes. Around 1946, the number of wind machines grew rapidly in southern California as a result of increases in oil-heater fuel and labor costs and the passage of smoke-nuisance ordinances by a pollution-conscious and rapidly-increasing urban population.

The modern wind machine consists of a steel tower 30- to 35-feet tall surmounted by a large horizontally-mounted fan or propeller oscillating in an arc ranging between 60° and 360° and driven by an electric, gas, or liquid-fueled engine. Modern frost protection in California is integrated with the wind machine or blower. Forced turbulence (or convection) has long been recognized to increase the efficiency of general heating methods. Since World War I, powerful, efficient, and dependable gasoline, diesel, and electric motors have been developed, and propeller technology has benefited from the development advances in aircraft and the science of aerodynamics. Efficient frost protection has been attained in southern California nine years out of ten, on the average, for the past twenty years, because of the development of reliable wind machines.

The gradual change in the philosophy of obtaining inversion layer air with vertically-mounted propellers on stationary bases to horizontally-mounted propellers on bases rotating through 360° at the rate of one rotation each 4 to 7 minutes has been the advance which has made the wind machine an effective modern frost-protection device.

Generally, wind machines are so designed that the updrift sector of the orchard is traversed in a short period, and longer times are given along rows and the downdrift sector. A dual wind machine (fig. 10–9, p. 348) installation will pass through 360° in 13 minutes and each part of the orchard will have received a blast each 6.5 minutes. A typical rotation schedule for one engine of a dual wind machine, where there is a northeast nocturnal air drift, is SE to NE, across rows, 1 min. 40 sec.; NE to NW, along rows, 4 min. 2 sec.; NW to SW, across rows, 1 min. 40 sec.; SW to SE, along rows, 5 min. 38 sec. (Turrell, Perry, Brooks *et al.,* 1956). The rate of turning must be so timed that the average rate of heat loss from the leaves is offset by the average heat gain from the ground-inversion mixture of air produced by the turning jet stream. The increase and decay of air temperature produced by the wind machine has been obtained at the mouth of a large wooden horn 12 feet above the ground updrift of a wind machine 196 feet distant (fig. 10–15). The blast duration varied from 0.66 to 1.77 minutes, while the average temperature jump was 3.98° F, a portion of the temperature increase lasting 6.2 minutes. The increase in inversion-layer temperature with sunrise was attended by an increase in the temperature of air entering the horn. The cyclic rise in air temperature was correlated with receipt of the wind machine blast. Confirmation of this response was obtained in Italy by Miller and Russo (1964).

The purpose of the wind machine is to produce enough turbulence to break up the temperature inversion of the air, mix the warm and cold components, transport the mixture, and at

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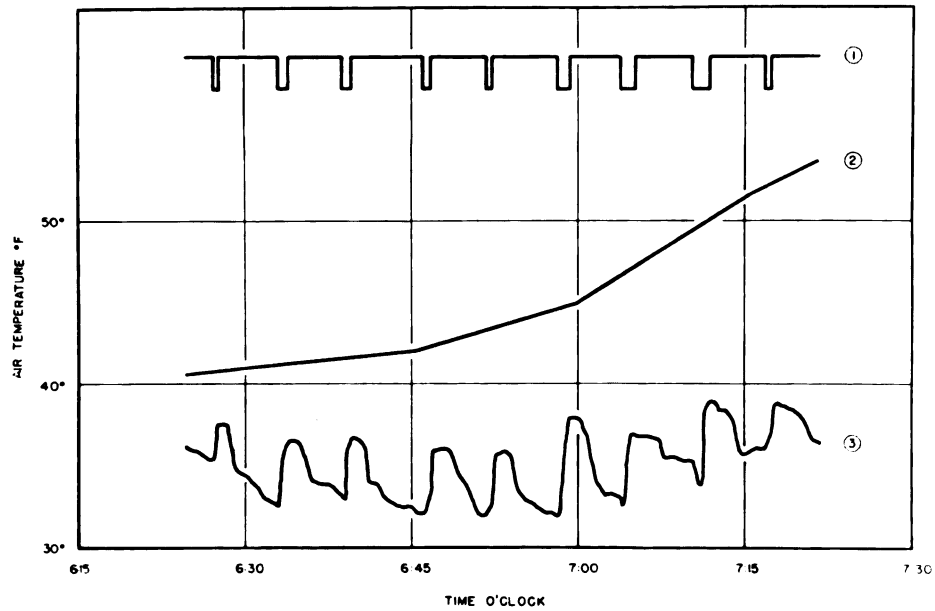

Fig. 10–15. Increase and decay of air temperature produced by wind machine at mouth of large wooden horn. Legend: (1) intervals and deviations of blast from 100-hp dual wind machine with aircraft-type propeller. Interval between blasts averaged 6.4 minutes, and duration of blast varied from 0.66 to 1.76 minutes; (2) inversion air temperatures were 46 feet above ground level, ranging from 8° F to 17.5° F above standard ground measurement; (3) air temperatures in mouth of a horn facing wind machine blasts. Tests conducted at Ventura, California, February 4, 1957. (Turrell, Austin, Perry *et al.*, 1958.)

the same time push the cold air out of the area. The thrust and reach of propellers in relation to the power source are important characteristics determining the efficiency of wind machines in accomplishing this purpose. The early wooden propeller was inefficient because of the large hub, and imperfections of pitch, blade-shape, etc., which were designed for moving a lifting object such as an aircraft wing surface. Highly efficient, present-day metal propellers are designed for static operation, creating turbulence and "reach" under relatively static conditions. Brooks, Rhoades, and Leonard (1952) showed that the amount of thrust was a readily measurable characteristic of wind machines and was directly related to the amount of frost protection afforded, judging by the increase of temperature in air at 5 feet above the ground surface.

Tests of the isothermal performance of several propellers were made by Griffiths and Hendershott (1961) in a very large aircraft hangar where there was no air drift, but some interference with ceiling and walls did occur. It can be seen in figure 10–16 that a medium-sized propeller (13 feet) running at a higher speed (rpm) has a greater reach than a larger, slower propeller (15.3 feet) having greater thrust. When these tests were corrected to 32° F, the four-bladed fan had a thrust of 734 lb and the two-bladed 1,000 lb. The smallest propeller (10 feet), running at slow speeds had the least reach. Cold air reduces the reach, which decreases on a cold night with an increase in air density and a decrease in viscosity.

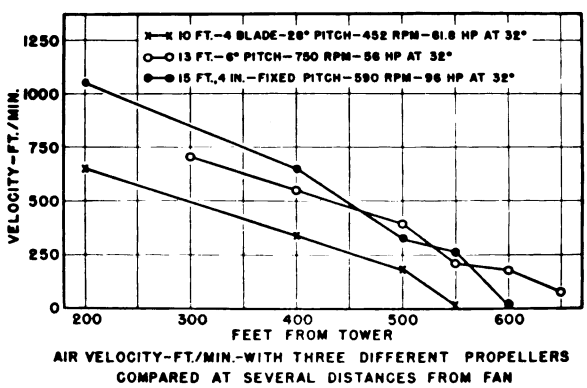

Fig. 10–16. The relationship between air velocity and reach of three different propellers. (From Griffiths and Hendershott, 1961.)

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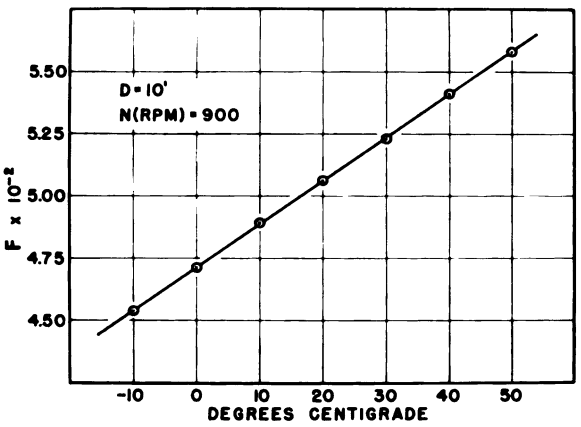

Fig. 10–17. Thrust (*F*) of a 12-foot U.S. wind machine propeller at different air temperatures, ranging from cold night temperatures to hot daytime temperatures.

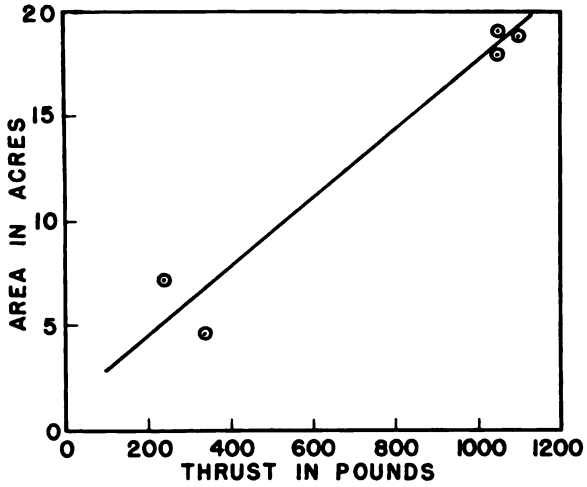

Fig. 10–18. Area in citrus orchards influenced by tower-mounted wind machines of different thrusts. (After fig. 1, Crawford, 1965.)

The thrust also decreases with decreases in air temperature as compared with a warm day (fig. 10–17). As air density decreases with increasing altitude the propeller will be less effective at a high altitude. For instance, a propeller absorbing 100 hp at sea level will absorb only 90 hp at 3,600 feet. Temperature changes of 10° F result in power changes of 2 per cent, a propeller absorbing 84 hp on a very warm day will absorb 100 hp on a very cold night (Anonymous, 1954). Growers should be wary of testing wind machines on hot days and expecting the same reach as on cold nights.

A powerful machine which has a reach of 500 feet on a warm day may have a reach of only 200 to 300 feet on a very cold night. Also, the turning (rotation) rate of the machine influences the effective reach. The more rapid the rate, the shorter the reach. In addition, the area protected by the wind machine varies in size and shape not only because of these factors, but because of the rate of nocturnal downhill drift of cold air. With no air drift, the protected area is nearly circular, but as the velocity increases the area becomes ovoid in shape, the upwind area becoming increasingly foreshortened with each increase in air velocity and the downwind increasingly lengthened (Brooks *et al.*, 1951). For a variety of conditions, as thrust increases, the area protected increases as shown in figure 10–18.

Generally, brake horsepower (bph) necessary for protection ranges from 5 to 8 bhp per acre. If there is a multiple installation of wind machines, or if they are on a slope, less bhp per acre is needed. Higher bhp per acre is needed in a cold spot, such as behind a cold dam with little air drainage. A 15-bhp wind machine is not powerful enough to take advantage of a large inversion, and may or may not protect 2 to 3 acres. Two or four wind machines running together provide greater temperature response per machine than one. A multiple installation of three 30-bhp machines may protect the same size area (11 to 18 acres) as one 90-bhp machine, but not with the same degree of protection as the 90-bhp machine, especially in low spots. The 90-bhp machine gives a larger percentage of higher temperatures (Brooks, Rhoades, and Leonard, 1952).

Wind machines, heavy ones at least, can move a sufficient volume of air (at a rate of 2.5 to 4.5 mph) to create turbulence in both the superior and inferior strata of the air similar to wind. Obviously, a wind machine alone will not give protection during the windy state of an advection freeze where winds vary from 4.5 to 30 mph, but together with heaters which are necessary for the wind stage, it can protect during the calm state when heaters alone are relatively ineffective (Turrell, Austin, Perry, 1965*a*; Turrell and Austin, 1960*b*). Brooks *et al.* (1961) assumed an area uniformly covered with dense cold air to ten feet above the tree tops. The wind machine was assumed to push the cold air in front of it until a pressure equilibrium was set up between the air from it and cold dense air outside the area. The machine rotating slowly produces new pressure areas at the edge of the old, producing a toroid-

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ally-shaped (bulging) air path. The pressure area ahead of the air jet projects radially outward; thus the warmer air replacing this must come from above. The turning speed of the jet must be such that the cold air envelope outside the area does not invade too far before being repressed. The turning time for 360° was discovered early to be between 4 to 6 minutes. Any additional forced turbulence would increase this eddy heat transfer downward, and the tendency is for the air from the propeller to remain near the trees because of entrainment of cold ground air. Supplying heat in the air stream increases its buoyancy, causing an upturn to occur sooner and thus decreases the reach.

One of the reasons early starting of the wind machine is effective is because the original inversion stratification is smaller before the ground air has had time to cool and the mixing pattern is set up with less dense air. This is particularly important with small machines without thrust sufficient to establish much mixing of extremely dense air.

Some equations and mathematical models describing factors affecting wind machine performance and functions are presented in Appendix III, p. 511.

Oil Heaters

Oil heaters have become the preferred means for heating citrus orchards. During the severe 1913 freeze in California, Teague (1944) showed that in a long advective freeze the oil heater was most efficient, gave longest burning times (and permitted short burnings when desired), was easily replenished, and was most adaptable to repeated usage. It was also easier to regulate than any of the other heat sources of the time. Because of those features, the citrus industry in southern California began to lean more and more toward the use of oil-fueled orchard heaters. Previously coal had been preferred over oil as well as wood, the latter having been used for hundreds of years to protect European orchards against frost and in the early years of the Florida citrus industry (Hume, 1907, 1926).

A satisfactory oil-fueled orchard heater must: (1) have sufficient capacity to burn all night without refilling; (2) have the capability of maintaining heat production even when fuel is low; (3) be reasonable in price; (4) be easy to disassemble, clean, and store; (5) be made so that when the heater burns dry no damage will result; (6) be easy to light under severe weather conditions; (7) be capable of delivering the heat fairly close to the ground; and (8) be capable of using all ordinarily available liquid heating fuels without producing too much smoke or leaving a heavy residue (Schoonover, Hodgson, and Young, 1930).

The last qualification is of increasing importance because of the worldwide concern over air pollution. Designing oil heaters to prevent air pollution has become a matter of legislation in some states. More and more citrus areas in California, for instance, are being made subject to smoke ordinances, and in these areas only approved "smokeless" heaters can be used. The ordinances generally limit smoke production to one gram of carbonaceous material per minute. Most of the oil-fuel heaters on the market are smokeless *if* kept clean. With the high cost of labor, cleaning those heaters not designed as smokeless becomes very uneconomical, so heaters which are nearly smokeless by design and thus

Table 10–2
APPROVED OIL-FUELED ORCHARD HEATERS AS LISTED BY THE RIVERSIDE COUNTY AIR POLLUTION CONTROL DISTRICT IN 1968–69.

Type	Maximum Hole Setting	Square Inch Equivalent
(1) Return stack	0.392	Two holes ½" diam.
(2) Pipe line	....•	.....•
(3) Jumbo cone	0.196	One hole ½" diam.
(4) 7" straight stack	0.606	One hole ⅞" diam.
(5) Lemora (spiral action)	0.606	One hole ⅞" diam.
(6) Lazy flame 24" stack	0.606	One hole ⅞" diam.
(7) Lazy flame 18" stack	1.212	Two holes ⅞" diam.
(8) Internal exchange (return)	0.392	Two holes ½" diam.

Source: Anonymous (1969).
• Must follow manufacturer's specifications for setting and fuel.

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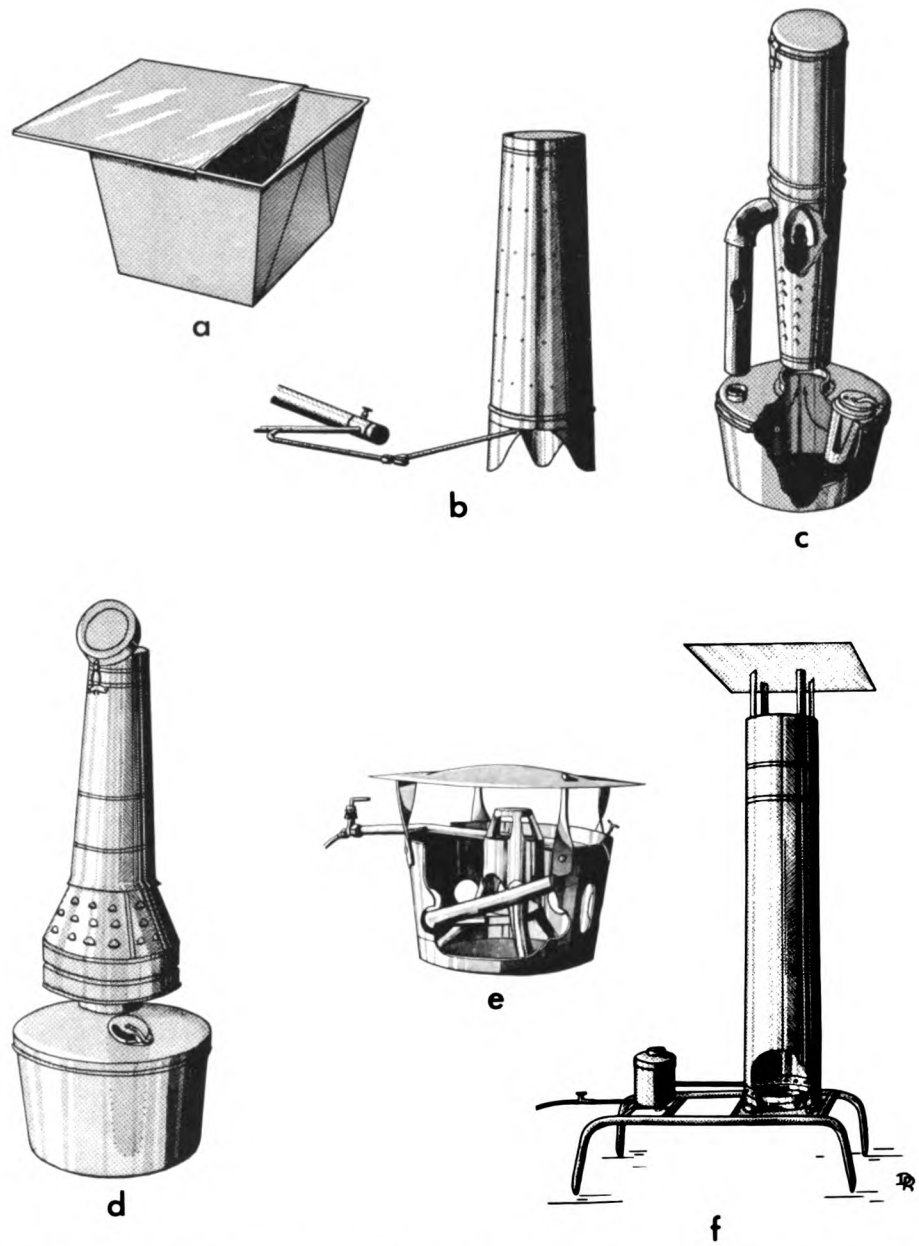

Fig. 10–19. Cutaway sections of approved oil-fueled orchard heaters. Legend: *a*, lard pail (not approved); *b*, Spot; *c*, return stack; *d*, jumbo cone; *e*, Fugit; *f*, Kittle.

need little cleaning are desirable. Many California air pollution control districts issue lists of approved heaters. California's Riverside County, for instance, lists eight heaters which are rated smokeless (at prescribed settings) and approved (table 10–2) and lists thirty-three kinds of orchard heaters that are not approved (Anonymous, 1969).

Some oil-fueled heaters are pictured in figure 10–19 and others are shown with accessories in figure 10–20 along with two briquette heaters for comparison. The *lard pail* (fig. 10–19), a version of which was used in California as far back as 1888, usually is fitted with a "spider" or flame spreader for use with the lighter oils. This heater, which requires refilling during long burns, has

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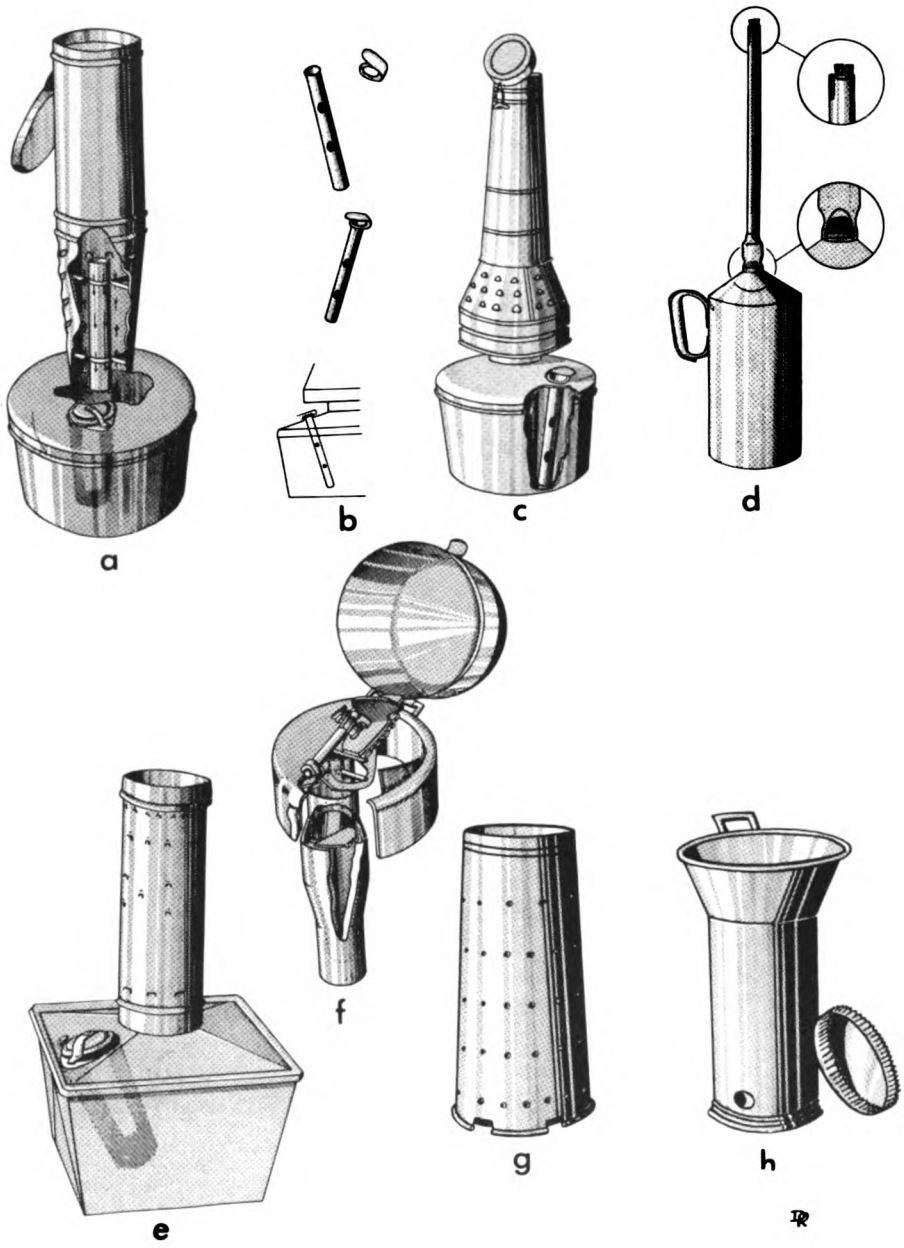

Fig. 10–20. Orchard heaters and orchard heater accessories. Legend: *a*, internal exchange; *b*, vent-tube regulator for preventing automatic decrease in burning rate; *c*, vent-tube regulator in place in bowl of a jumbo cone heater showing how, as fuel decreases, more holes are exposed and the increase in air keeps burning rate at former level; *d*, standard type lighting torch of 6-quart capacity showing wick and safety screen at either end of spout; *e*, lazy flame heater with 18-inch stack and square bowl; *f*, automatic bimetallic thermoregulator showing large sleeve into which "L"-shaped lever tilts when expanded by heat, permitting cover to lower over entrance to bowl and decrease air supply; *g*, briquette heater; *h*, briquette heater with funnel to facilitate filling, and lid.

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a capacity of 5 to 10 quarts, burns at a low flame temperature (645° F to 1070° F), requires 27° Baumé or higher fuel oil, and emits a good deal of smoke. Lard-pail heaters adequately protected large grapefruit trees in Florida during the 1962 advective freeze. An improved version of the lard pail is the "fat stack," made with a six-gallon pail fitted with a large stack.

In contrast with the crude lard-pail heater, the *return-stack heater* is far more sophisticated and has been widely accepted as an almost smokeless and a very efficient heat source (fig. 10–19).

The return-stack heater was developed by A. S. Leonard of the University of California in 1949 and 1950 (Leonard, 1951). He had demonstrated ten years previously (Leonard and Boelter, 1942) that inert gases such as nitrogen, carbon dioxide, and water vapor, which are normally formed in the combustion of hydrocarbon fuels, were effective in reducing the smokiness of acetylene and benzene flames. Thus, making a smokeless orchard heater simply meant adapting a standard orchard heater to utilize some of its stack gases to mix with the fuel vapor in the bowl before it reached the flame. This was accomplished by adding a tube from stack to bowl. As presently manufactured, the heater has a standard 9-gallon round bowl. The bowl cover is standard except for the return-tube connector. The combustion chamber and stack are made of galvanized iron and consist of a louvered combustion-chamber section, tapering from 6 to 8¼ inches in diameter, and a cylindrical stack section 8¼ inches in diameter. The return tube is 3 inches in diameter and is made of the same material (fig. 10–19). The gas-return scoop, which extends to the axis of the combustion chamber, is made of cast iron to insure a long life. The standard downdraft tube is used in the bowl to insure quick and easy lighting. Lighting is done with a torch in the usual way. The heater will burn ⅜ to less than ½ gallon per hour with the draft regulator closed, and 1 gallon per hour when partly open, producing less than 1/10 gm of carbonaceous material per minute.

The *pipe line heater* has taken many forms (Kaup, 1937). In southern California, these heaters have been produced for many years. The Kittle and Fugit are examples where the burner and oil reservoir are separate (fig. 10–19). The Kittle uses a gravity feed, while others use a vacuum or a pressure feed. Clean oil of constant composition is burned, and the approved types are nearly smokeless. The gravity feed has the disadvantage that fuel is delivered to the burner only half as fast when the fuel is low as when full. Thus the heaters must be filled every day.

Economic conditions in general, especially the unavailability and high cost of labor, together with demands for air pollution control, presently are forcing growers more and more to complete automation of their frost-protection systems. The centrally fueled and controlled pipe line oil heaters with or without automatic lighting are readily adaptable for this because of new materials such as PVC pipe and plastic tank liners. Schue Products Co. of Upland, California, has developed a Hy-Lo fully-automated system employing a low pressure (20 to 120 psi) oil feed. A new heater similar to the return-stack is used which is said to be smokeless. Old conventional model return-stack heaters or large cone heaters with empty oil bowls can be adapted by removing the down draft tube and cap, putting the converter cap on the 4-inch nozzle in place of the regulator, and tapping the oil and electrical lines into the conventional cap. Forty heaters, each producing 70,000 to 140,000 BTU/hr may be automatically operated from a single fuel tank and a single control station.

Spot Heaters (fig. 10–19) are smokeless heaters of recent development with high pressure (100 to 200 psi) feeds. They are capable of producing from 85,600 to 201,960 BTU per heater per hour, depending on the pressure and which of three fuels is used (No. 2 fuel or diesel oil, L-P gas, or natural gas). The Spot Heater consists of a perforated, conical, metal stack, 10 inches in diameter at the base, 7½ inches in diameter at the top, and 32 inches tall, set on a metal base to which is attached a patented burner mounted on a metal tube. The metal tube prevents the burner from carbonizing the fuel by keeping the burner cool and not permitting it to reach oil-cracking temperatures. It is connected by ¼-inch plastic tubing feeder lines to a central pump where fuel delivery is controlled. A storage tank is necessary as with other pipeline heaters if oil is used.

Other types of oil-fueled heaters are jumbo cone (fig. 10–19), the 7-inch straight-stack (not illustrated), the internal exchange (fig. 10–20), and the lazy flame 18-inch stack (fig. 10–20).

Solid-Fuel Heaters

Briquettes.—The use of solid-fuel heaters went into decline after the 1910 freeze. Coal baskets, coal heaters, and coal grates were gradually replaced because of the time-consuming processes of servicing, lighting, and extinguish-

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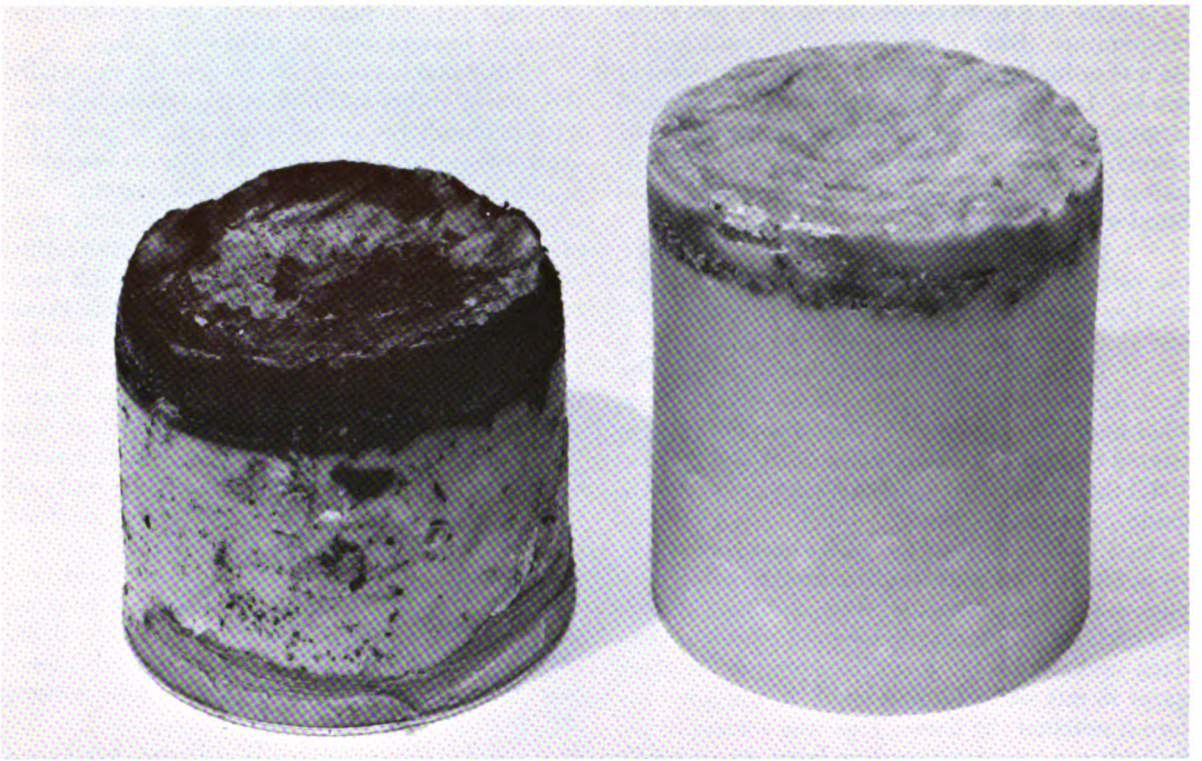

Fig. 10–21. Left, 266,000 BTU Texaco orchard heater after burning 12 hours. Most of the two-gallon, paper ice cream carton has been removed. Right, 8-inch diameter and 10-inch-high paper container has been removed to show layer of wicking material at top and fourteen pounds of wax below.

ing them. About a decade later, interest in solid fuels was revived when Young (1923) tested carbon briquettes in two types of heaters and found the briquettes superior to coal.

Briquette heaters distributed at one hundred to the acre are equal to fifty oil heaters per acre. Two different briquette heaters are shown in figure 10–20. To maintain combustion, grates or other porous supports are needed under briquettes—as well as under pressed wood and charcoal. Russian citrus growers have tried grates for burning pressed peat (Khidasheli, Nadaraga, and Lomiya, 1959).

Wax Candles.—Solid-fuel heaters, including wax candles, again received considerable attention after the 1962 Texas and Florida freezes (Gerber, 1966). Wax candles are produced in many sizes by a number of oil companies (Miller, Turrell, and Austin, 1966) that formerly had found little market for the wax resulting from oil refining. These companies are now putting the wax into cartons with certain wicking materials, to make wax candles. The greater the candle's burning area, the greater the heat production per unit of time. The greater the candle height, the longer the burning period.

Chevron Oil Co. makes the Ortho Krop Heater, which is packed in a carton 10 inches in diameter and 13 inches high. It contains 25 pounds of wax and produces a total of 475,000 BTU, delivering 40,000 to 59,000 BTU/hr for 8 to 12 hours. It must be protected from rain, but can be snuffed out and relit. Gulf Oil Co. produces a similar orchard heater, the Citrus Candle, which contains $9\frac{1}{2}$ pounds of wax and burns about $4\frac{1}{2}$ hours. Texaco Co. produces the Texaco Orchard Heater (fig. 10–21), a paraffin base candle, weighing 14 pounds, in a cylindrical 2-gallon paper carton, 8 inches in diameter and $9\frac{3}{8}$ inches high. It yields a total of 266,000 BTU or 33,000 BTU/hr for 8 hours. Heating trials on the Texaco heater were made by Maxwell and Bailey (1965) and Miller (1966).

Humble Oil Company uses a 14-pound wax bar measuring 12 by 17 by $2\frac{3}{4}$ inches, in a galvanized-iron tray with a two-part sliding top (fig. 10–22). The wick is rock wool, located in the cen-

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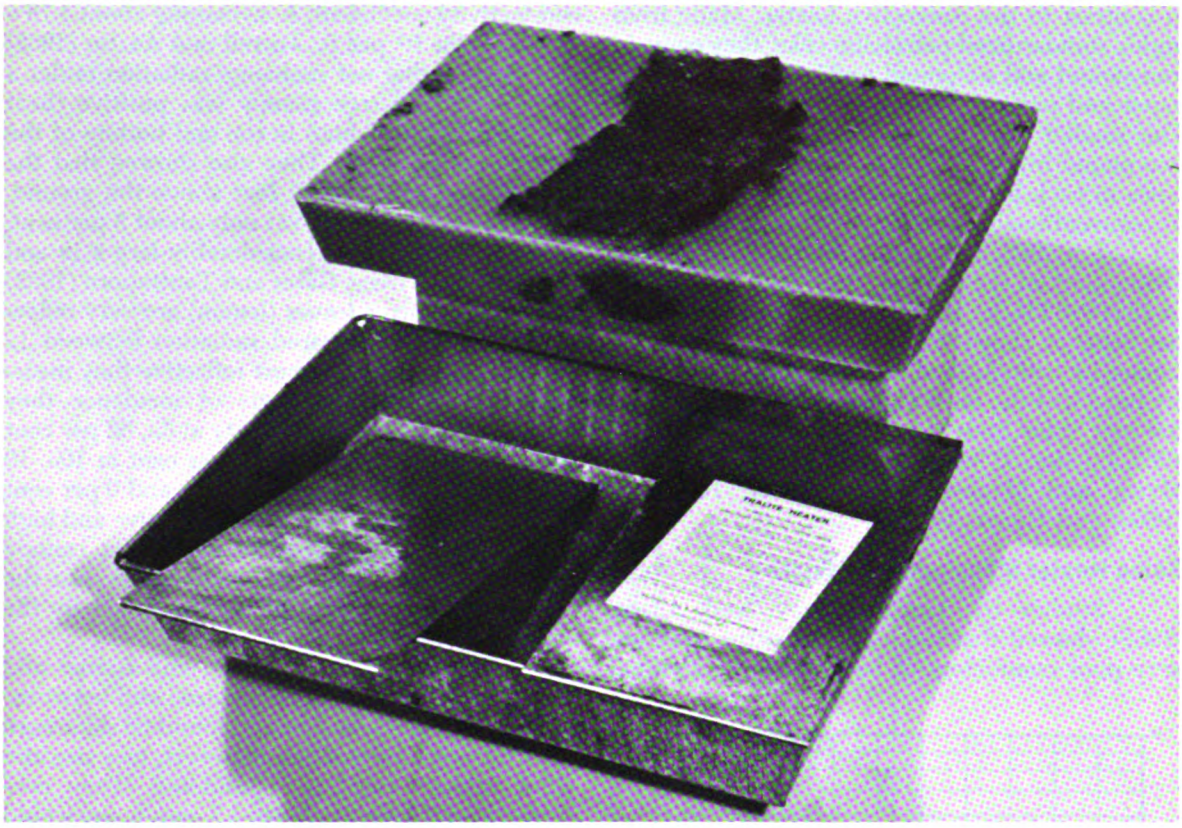

Fig. 10–22. The Humble Oil Company's Tralite heater. Below, galvanized iron pan and two-part sliding cover. Above, 14-pound wax cake (12 by 17 by 2¾ inches), which yields 20,000 to 25,000 BTU/hour for ten hours. Wicking material is in center of block.

ter of the wax bar. The heater is extinguishable, relightable, and refillable. It yields a total of 220,000 BTU and burns approximately ten hours, emitting about 20,000 to 25,000 BTU/hr (Maxwell and Bailey, 1965).

Sinclair Refining Company markets a heater with similar characteristics. Ten pounds of petroleum are packed and burned in a concrete, plastic-coated block, measuring 7¾ by 9¼ by 9¼ inches. A paper cross in the top of the wax improves ignition, and combustion is maintained by the wicking action of the concrete. It yields a total of 200,000 BTU at the rate of about 20,000 BTU/hr. The heaters necessary to protect one acre of orchard can be remotely lighted by a 12-volt storage battery wired to standard 5-minute railroad flares placed on tops of the heaters. The heaters can be extinguished by placing metal trays over them.

Petroleum Coke Bricks.—Mobil Oil Company manufactures a radiant heater, Tree-Heet,

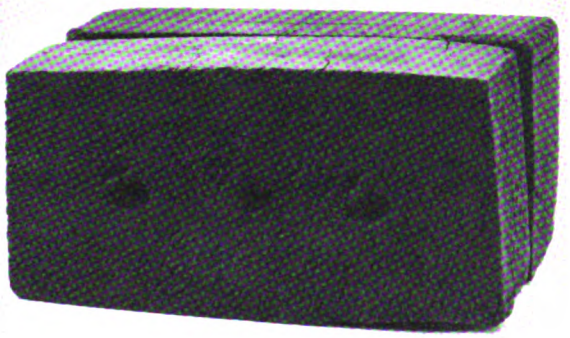

Fig. 10–23. The Mobil Oil Co. petroleum coke blocks, 4 pounds total (8 by 4 by 2 inches) yields 48,000 BTU, burns 4 to 4½ hours. Estimated to yield about 25 per cent of its heat as radiant heat. (Gerber, 1969.)

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in contrast to the convective heater. Made from highly standardized petroleum coke, they come in four-pound and six-pound units, wrapped in wax paper and packaged in waterproof polyethylene. The smaller unit consists of two standard size two-pound bricks, 8 by 4 by 2 inches, with three holes in each brick (fig. 10–23). They are lighted by conventional methods or by a flamethrower (pl. I, *B*, p. 380), and yield a total of 48,000 BTU. Depending on the burning rate, they give 10,000 to 12,000 BTU/hr, mostly radiant heat (about 25 per cent) as shown in plate I, *C* (p. 380). They cannot be extinguished and relighted. Tree heaters have had the most extensive testing of any of the new solid fuels (Leyden, Hensz, and Fucik, 1965; Leyden, Hensz, and Fucik, 1966; Wiegand, Myers, and Maxwell, 1966; Gerber, 1966 and 1969*a;* and Hensz, 1969).

Some Heater Management Factors

Studies by Turrell, Peavy, and Austin (1967), showed that the leaves of citrus trees are very poor conductors of heat, having a thermal conductivity coefficient, *K*, averaging about 4.78×10^{-2} BTU/hr ft^2 per ft. Turrell and Austin (1965) also showed that net exchange radiation under a large grapefruit tree canopy was positive (heat was being gained) both in top and bottom of the tree on a cold night. They also showed that the heat loss by radiation, 2 feet above the ground, between such big trees was only about 5 per cent, although the loss was considerably larger in and between small trees. Gates and Tantraporn (1952) showed that citrus leaves (lemon) are very reflective to longwave infrared radiation between 1μ and 25μ, and were the most reflective they measured. At a 65-degree angle of incidence they measured 6 per cent reflectivity at 3μ, 82 per cent at 5μ, 14 per cent at 7.5μ, 17 per cent at 10μ, 10 per cent at 15μ, 11 per cent at 20μ, and 9 per cent at 25μ. Thus the low thermal conductive and high thermal reflective properties make the canopy an efficient insulated top to effectively use the relatively small amount of heat supplied by the solid-fuel heaters.

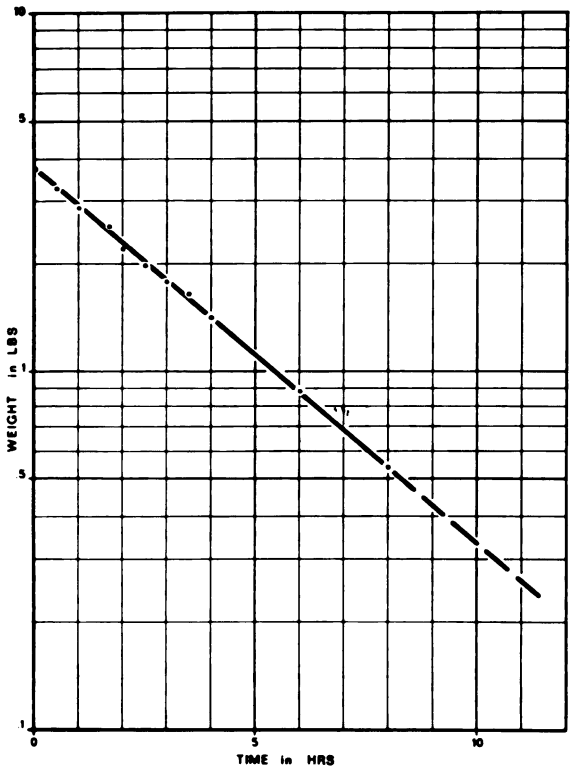

Fig. 10–24. Successive weights, less weight of moisture, during burning of a pair of petroleum coke blocks. Original weights immediately after lighting not shown. (Courtesy of R. L. Perry.)

Barnes and Frost (1966), and Barnes and Frost (1969) studied under-the-tree and between-the-tree heater placement and found no difference in results on a quiet night. However, tree size and wind velocity must be considered. They concluded that 0.6 man-hours to 1.7 man-hours would be required per hundred trees to distribute from one to six packages per tree at the tree skirts. An additional 0.8 man-hours per hundred cartons are required for opening and disposing of the cartons. Lighting requires 15 minutes per hundred trees at one package per tree to twice the time for six packages per tree when placement is at the tree skirts. The temperature increase at 5 feet above the ground is about 1.5° F to 2° F per package per tree, with a 9° F increase when six packages per tree are distributed around the tree skirts in pairs. Size of tree and wind velocity will modify the temperature expected. Like coal and coke, petroleum coke requires 20 or 30 minutes to produce sizeable quantities of heat, and, after a maximum is reached, heat production declines throughout the remainder of the burning period. This is shown for a pair of petroleum coke bricks weighing 4 lb to start (fig. 10–24). The graph indicates that the amount of fuel left at the end of any burning time is proportional to the weight at the start of burning time. The graph may be easily converted to show the number of BTU left at the end of any burning time. When severity of the freeze dictates renewing or increasing the fuel, the process may be greatly accelerated by using a

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Table 10–3
A COMPARISON OF MAJOR GROVE-HEATING SYSTEMS

System	Radiant Heat	Effectiveness			Air Pollution	Efficiency (BTU/Degree Temp. Rise)	Costs		
		With Low Ceiling	With High Ceiling	As Border Heater			Fixed Capital	Fuel	Labor
Lard pail*	Poor	Good	Poor	Good	Poor	Poor	Good	Fair	Fair
Lazy flame	Fair	Good	Poor	Fair	Fair	Poor	Fair	Good	Fair
Jumbo cone	Good	Excellent	Fair	Poor	Good	Fair	Poor	Good	Fair
Return stack (gas or oil)	Good	Excellent	Fair	Poor	Good	Fair	Poor	Good	Fair
Pipeline	Fair	Excellent	Poor	Good	Fair	Fair	Poor	Good	Good
Wax candles	Poor	Good	Poor	Good	Poor	Fair	Excellent	Poor	Poor
Wind machines	Poor	Excellent	Poor	Poor	Excellent	Excellent	Poor	Excellent	Excellent
Wind machines and heaters	Fair	Excellent	Good	Good	Good	Excellent	Poor	Excellent	Good
Petroleum coke bricks	Excellent	Excellent	Excellent	Excellent	Good	Excellent	Excellent	Poor	Fair
Heaters and petroleum coke bricks	Good	Excellent	Excellent	Excellent	Good	Good	Fair	Good	Fair
Wind machines and petroleum coke bricks	Fair	Excellent	Good	Excellent	Good	Excellent	Poor	Excellent	Good

Source: Albrecht (1967).
* Not acceptable where smoke controls exist.

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Table 10–4
FUEL INPUT AND HEAT OUTPUT, TEMPERATURE AND VELOCITY OF STACK GASES, AND SMOKE PRODUCTION OF SOME ORCHARD HEATERS.

Kind of Heater	Fuel Charge (Lb)	Fuel Usage (Lb/Hr)	Heat Release Rate of Fuel (BTU/Hr)	Maximum Upward Velocity of Stack Gases (Mph)	Temperature of Gases (°F)	Smoke from Stack Gas (Lb/1,000 Ft³)
			Solid-Fuel Heaters			
Briquette No. 1†	8	1.68	23,000	2.5	600	trace
Briquette No. 2†	10	2.50	34,000	2.4	665	clear
Briquette No. 3†	26	4.63	75,000	1.7	494	0.0053
			Oil-Fuel Heaters			
Lard pail*	8	3.28	65,000	2.2	702	0.0204
Return stack	67	5.60	105,000	2.7	1,200	clear
Jumbo cone	27	6.75	138,000	6.3	884	clear
Lazy flame, medium stack	38	5.25	104,000	4.6	1,261	trace
Lazy flame, tall stack	8	3.26	64,000	6.9	792	clear
Pipeline, Kittle	51	5.25	104,000	1.7	834	0.0107
70 psi pipeline, Spot Heater	....	5.25	102,000	6.2	315	0.0000199
100 psi pipeline, Spot Heater	....	6.17	120,000	5.9	265	0.0000156
200 psi pipeline, Spot Heater	....	8.58	167,000	5.9	285	0.0000123

Source: Hoffman (1927) and Truesdail Laboratories, Inc. (1967).
* Heater not approved in California.
† Not used since 1950–1955.

motorized vehicle with two metal chutes projecting from the rear of the bed. This can be driven down between the tree rows while blocks lighted in the chutes can be fed under the trees in each row simultaneously (Anonymous, 1971*c*).

Comparison of Heaters and Fuels

No single method of frost protection is flawless. Each method has weaknesses as well as strengths. Nor can any system be judged best for all conditions or all orchard locations. A comparison of modern grove heating systems made by Albrecht (1967) is summarized in table 10–3. Albrecht evaluated each system in terms of nine different characteristics, rating them with numerical values as poor (1), fair (2), good (3), and excellent (4). Afterwards he totalled the rating values given to each characteristic to provide an overall numerical evaluation. Since these overall evaluations appear to be applicable only to Florida terrestrial and atmospheric freeze conditions, they are not shown in table 10–3.

Fuel input and heat output of some heaters is given in table 10–4, together with the maximum upward velocity that gases have at the top of the stack for a given fuel rate use and charge (Hoffman, 1927). Smoke production has been limited to one gram per minute or 0.0352 oz./min. in many localities in California. Smoke production can be roughly calculated from the table. From this table also, a practical idea of the interplay of vector forces between stack-gas velocity and wind velocity may be obtained and the windbreak effect of lines of upwind heaters may be estimated. Pipkin and Sliepcevich (1964) determined the degree that gas flames of various diameters were tilted by wind of 0.3 to 2.4 miles per hour. The two heaviest factors were wind drag and buoyancy. They found the logarithm of the wind-drag coefficient plotted against the logarithm of the Reynolds number was linear after the flame angle of tilt was extracted. They presented a model of flame bending by wind that may be useful in frost-protection studies.

Plume heights of buoyant hot gases from orchard heaters in still air under frost conditions were studied using model and schlieren techniques by Crawford and Leonard (1962). This height was found to range from 35 to 60 feet (fig. 10–25) under strong inversion conditions (14° F) and from 75 to 130 feet under mild inversion conditions (2° F) (Crawford and Leonard, 1961).

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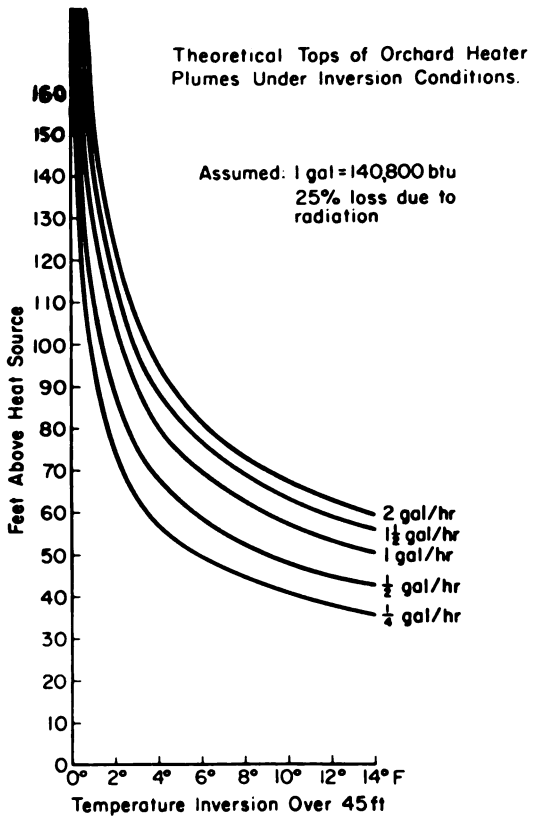

Fig. 10–25. Heights of orchard heater plumes predicted from scale model studies as a function of fuel oil consumption and temperature increase for 45 feet upward from heater. (From Crawford and Leonard, 1961.)

In addition, they found the greater the amount of heat supplied, the greater the height of the plume, thus supplying the basis for maintaining "many small fires rather than a few large ones."

Radiation characteristics of some heaters are shown in table 10–5. The energy absorbed by medium-sized and large trees is shown to be about equally distributed between ground, tree, and sky for trees of 12-foot height and diameter. In the case of under-the-tree heating with new solid fuels (table 10–5), radiation to the sky would be zero and the first distribution between soil and tree canopy would be 12.5 per cent each; reradiation from the ground surface would establish a flow largely toward the tree canopy. Radiant energy from a heater passes through the plant—foliage, fruit, wood—in its "view," and thus offers the most efficient protection against advection freezes. It is possible, however, for the combination of air temperature and wind velocity to kill all foliage on a tree except that nearest a good radiation heater, as shown in plate I, *D* (p. 380). This situation strongly suggests the need of a windbreak. Reduction of wind velocity by half might conceivably reduce the cooling effect to within the protective ability of the heaters.

Both convective heat with attendant tendency toward chimney effects and radiant heat are functions of the rate of fuel consumption or, in other words, temperature. An estimate (to 125° F) of stack temperature can be obtained visually from its color: lowest visible red = 887° F; dull red = 1,022° F to 1,157° F; full cherry red = 1,291° F; light red = 1,562° F; orange = 1,652° F; full yellow = 1,742° F to 1,832° F; and white = 2,102° F and upwards (Weber, 1941).

The characteristics of some California orchard-heater fuels are given in table 10–6 and heats of combustion of the various fuels are given in table 10–7, together with the amounts of heat from some of the other sources of heat in the orchard.

OTHER FROST-PROTECTION METHODS

Gas Heaters

The difficulty in securing adequate manpower to light, refill, and service heaters, and the mounting costs of labor add up to one of the most serious drawbacks to many orchard-heating systems. One way of solving this labor problem is to install an automated or semiautomated gas pipeline system.

It has been estimated that with a gas pipeline system as many as four hundred heaters can be lighted simultaneously. Although natural gas is the lowest cost fuel, certain commercially processed gases also are economical. Gas heaters are simple, easily operated, and nearly smokeless. They require little cleaning, and the small amount of maintenance work necessary can be scheduled for times when other grove work is at a minimum. Some disadvantages of a gas pipeline system are the relatively high cost of installation, the necessity for depending on the cooperation of a gas company to ensure adequate supplies during cold spells, and the possibility of buried pipelines interfering with other grove operations.

Although portable bottle gas heaters are marketed, the main interest in gas heaters lies with permanently installed pipeline systems. In many places where citrus is grown, natural gas is the least expensive heating fuel and can be used (with cooperation of the local natural gas company) in a network of pipes with a system of con-

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Table 10–5
RADIATION OUTPUT FROM APPROVED ORCHARD HEATERS

Kind of Heater	Burning Rate (Lb/Hr)	Total from Heater	Radiant Fractions (Per Cent of Total Fuel Energy*) 12′ × 12′ Trees To Ground	To Trees	To Sky	16′ × 16′ Trees To Ground	To Trees	To Sky
Solid Fuel Heaters								
Exper. Coke	5.4	41.7	13.6	13.3	14.8	13.0	20.3	8.4
Tree-Heet†	1.0	25.	.....	.....	.....	.....	.....	.....
Oil-Fuel Heaters in Centers of Tree Spaces (20′ × 24′ Tree Spacing)								
Lard pail‡	4.9	4.9	.....	.....	.....	.....	.....	.....
	1.5	2.1	.....	.....	.....	.....	.....	.....
Return stack§	5.4	27.6	9.8	8.9	8.9	8.7	14.1	4.8
Jumbo cone§	5.6	29.6	10.7	9.8	9.1	9.3	15.4	4.9
Lazy flame, medium stack	5.3	2.2	.....	.....	.....	.....	.....	.....
Lazy flame, tall stack	3.3	1.6	.....	.....	.....	.....	.....	.....
Pipe line, Kittle	5.7	27.5	12.0	8.6	6.9	10.6	13.8	3.1
Pipe line, Fugit	8.1	18.1	8.8	4.4	4.9	8.5	6.8	2.8
Pipe line, Spot Heater	5.3	29.4	.....	.....	.....	.....	.....	.....
Pipe line, Spot Heater	6.2	27.5	.....	.....	.....	.....	.....	.....
Pipe line, Spot Heater	8.6	31.2	.....	.....	.....	.....	.....	.....

Source: Kepner (1951), Hoffman (1927), and Truesdail Laboratories, Inc. (1967).
* For lower burning rates, radiant fractions are slightly less; for greater rates fractions are constant.
† Personal communication on radiation from Tree-Heet from J. F. Gerber.
‡ Not an approved heater in California.
§ Approximate characteristics also as pipe line heaters as adapted by Schue Co.

Table 10–6
STANDARD LIMITS OF STOVE OIL GRADES FOR GENERATOR-TYPE HEATERS AND DIESEL FUEL GRADES FOR DISTILLING-TYPE HEATERS

Standard Limits of Stove Oil Grades Represented by Pacific Standard 100 and Commercial Standard No. 1. for Generator-Type Heaters

Characteristics	Pacific Standard 100 Maximum	Pacific Standard 100 Minimum	Commercial Standard No. 1 Maximum	Commercial Standard No. 1 Minimum	Observed Range for 3 Samples of Pacific Standard 100, April, 1937
Gravity at 60°/60° F‖, A.P.I. (American Petroleum Institute)	.....	.....	.....	.....	38.3 to 37.0
Viscosity at 100° F (seconds, Saybolt Universal)	.....	.....	.....	.....	34 to 31
Pour point (°F)	.....	.....	0‖	.....	0 to –20
Conradson carbon (per cent by weight)	.....	.....	.....	.....	0.02 to 0.01
Conradson carbon on 10 per cent residuum (per cent by weight)	.....	.....	0.12#	.....	.....

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Table 10–6 continued

Characteristics		Pacific Standard 100		Commercial Standard No. 1		Observed Range for 3 Samples of Pacific Standard 100, April, 1937
		Maximum	Minimum	Maximum	Minimum	
Flash, Pensky-Martens, closed cup (°F)		165	110 (or legal)	165	100 (or legal)	180 to 145
Distillation American Society for Testing Materials	Initial boiling point (°F)	.....	.....	.....	.....	381 to 359
	10 per cent by volume (°F)	420	350	410	.....	405 to 383
	50 per cent by volume (°F)	.....	.....	.....	.....	451 to 429
	90 per cent by volume (°F)	550	450	.....	.....	520 to 495
	End-point (°F)	.....	.....	590••	.....	600 to 558
Distillation residue (per cent)		.....	.....	.....	.....	2.0 to 1.5
Water and sediment (per cent)		.....	.....	trace	.....	trace
Sulfur (per cent)		.....	.....	0.5††	.....	.....

Standard Limits of the Diesel-Fuel Grades Represented by Pacific Standard 200 and Commercial Standard No. 3, for Bowl or Distilling-Type Heaters

Characteristics		Pacific Standard 200 and Suggested Limits		Commercial Standard No. 3		Observed Range for 7 Samples of Pacific Standard 200, May, 1938
		Maximum	Minimum	Maximum	Minimum	
Gravity at 60°/60° F•, A.P.I. (American Petroleum Institute,		.....	27•	.....	.....	34.5 to 30.3
Viscosity at 100° F (seconds Saybolt Universal)		55	35	55	.....	39.7 to 35.7
Viscosity at 35° F (seconds Saybolt Universal)		80•	.....	.....	.....	79.5 to 54.5
Pour point (°F)		0•	0†	.....	.....	+5 to –45
Pour point on 25 per cent bottoms (°F)		.....	.....	.....	.....	+60 to –10
Open crucible self-burning residue (per cent by weight)		.....	.....	.....	.....	1.21 to 0.76
Conradson carbon (per cent by weight)		.....	.....	0.15	.....	0.073 to 0.016
Conradson carbon on 10 per cent residuum, (per cent by weight)		1.00•	.....	.....	.....	0.60 to 0.08
Flash point, Pensky-Martens, closed cup (°F)		.....	150	230	110	214 to 172
Distillation American Society for Testing Materials, D158-28	Initial boiling point (°F)	.....	.....	.....	.....	438 to 370
	10 per cent by volume (°F)	.....	425	.....	.....	485 to 440
	50 per cent by volume (°F)	.....	.....	.....	.....	542 to 498
	90 per cent by volume (°F)	.....	600	675	600‡	668 to 603
	End-point (°F)	.....	.....	.....	.....	732 to 661
Distillation residue at 700° F (per cent)		.....	.....	.....	.....	6 to 2
Water and sediment (per cent)		0.10•	.....	0.10	.....	.....
Sulfur (per cent)		0.75•	.....	0.75§	.....	.....

Source: Schoonover *et al.* (1939).

• Additional limits suggested by the authors (not listed in the general standard) for orchard-heater fuel, pending further studies.

† Specification limit when low pour point is required.

‡ Minimum distillation of 600° may be waived if A.P.I. gravity is 26° or lower.

§ Specification limit when low sulfur content is needed.

‖ Limit when low pour point is needed.

Limit is 0.05 per cent for sleeve-type, blue-flame household burners.

•• Limit is 560° F for sleeve-type, blue-flame household burners.

†† Limit when oil of low sulfur content is needed.

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Table 10–7
HEATS OF COMBUSTION OF FUELS AND HEAT PRODUCTION BY HEAT SOURCES USED IN CITRUS ORCHARDS FOR FROST PROTECTION

Energy Source	BTU/Lb.	BTU/Ft.³
Butane gas*	21,180	3,261
Charcoal	13,530	.....
Coal	6,580 to 14,780	.....
Coke	12,527 to 14,111	.....
Coke-gas	.....	514 to 574
Crude oil	18,755 to 19,510	.....
Diesel oil	18,835 to 19,376	.....
Electricity†	.....	.....
Natural gas	.....	1,021 to 1,129
Paraffin oil	17,640	.....
Paraffin wax	18,540 to 19,980	.....
Peat	7,040	.....
Pitch	16,900	.....
Propane gas	19,944 to 21,560	2,522
Wood	6,300 to 8,300	.....
Rubber	6,028	.....

	BTU/Lb.	Total BTU	BTU/Hr.	BTU/Lb. °F
Air (dry, 1 atm, 32° F)	.....	.....	.....	0.240
Air (saturated, 1 atm, 32° F)	.....	.....	.....	0.242
Fog§	.....	.....	.....	.....
Return-stack orchard heater	.....	1,260,000	140,000	.....
Slide-top heater	.....	1,260,000	84,000 to 172,000	.....
Soil (sand, dry)	.....	.....	.....	19.6 0.19
Soil (sand, wet)	.....	.....	.....	26.2 0.24
Soil (sandy peat, dry)	.....	.....	.....	0.33
Soil (sandy peat, wet)	.....	.....	.....	.....
Steam (saturated, 1 atm + 4.6 mm Hg) 32° F	1,018	65,000‡	.....	0.45
Texaco orchard heater (candle)	.....	259,560	32,500	.....
Tralite	.....	222,560	22,000	.....
Tree-Heet (2 blocks)	.....	48,000	12,000	.....
Water vapor	.....	.....	.....	.....

Source: Baumeister and Marks (1964), List (1966), Brooks (1957), Durrenburger 1956), Hall (1915).

* Butane-propane, 1¼ gal. = 140,000 BTU = 1 gal. oil.

† Forty-one kilowatt hours = 140,000 BTU = 1 gal. oil (Schoonover, Brooks, and Walker, 1939).

‡ Per ft.³ of condensed steam.

§ See special section on fog (p. 371).

trol valves (Barker, 1964). The pipes may be galvanized iron (or iron treated in another manner) or plastic, and the simple burners themselves may or may not be equipped with stacks (Hoon, 1966; Ure, 1969; Barker, 1964; Lamade, 1967).

Natural gas systems with galvanized-iron pipe have been installed by a large citrus development in the San Joaquin Valley of California (Platt, 1965). Similar natural gas-heating systems have been installed in other kinds of orchards in other climates. For instance, a three-acre deciduous orchard in Summerland, British Columbia, was equipped with a natural gas-heating system supplied directly from a 2-inch diameter main. A 1½-inch diameter service line 10 feet long from the main carried the gas to a Roots-type meter for measuring the gas in conjunction with a base pressure index. Gas was fed into the orchard system made up of 1½-inch diameter headers and ¾-inch diameter laterals. The steel pipe sections were welded, coated, and wrapped before being buried. The gas burners had no regulators, but the pressure was reduced from 25 psi to 8 inches water column by two small orifices in the burner

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heads. Heat from the burners was deflected horizontally by metal plates mounted on three legs. The gas was turned on at the meter, and lighting of the burners was done manually with a propane torch (Barker, 1964). The installation was made with the cooperation of two local gas companies.

A number of types of propane, liquid petroleum, and natural gas orchard-heater systems have been installed in Washington (Hoon, 1966), California (Sutter, 1962), Texas (Young, 1925), Arizona (Konrad, 1964), and Florida (Yelenosky and Horanic, 1966; and Harrison and Gerber, 1966). Propane and liquid petroleum gas systems are more popular than natural gas installations and have received more testing. Distribution of the propane and liquid petroleum gases is generally through a network of polyvinyl chloride (PVC) plastic pipes having a 160-psi rating. The plastic piping may be laid on the ground or buried 18 inches or more.

Open-flame gas burners giving mostly convective heat have been used in many gas systems, but enclosed burners emitting both radiant and convective heat are considered to give the best results. The Spot Heater used on the West Coast is an example of a heater with an excellent burner and a radiant shield (Lamade, 1967). Some heaters are designed to supply convective heat under the tree, such as the Hurd-Superheater manufactured in Florida which is similar to the Spot Heater, but without a radiant shield as is the propane-fueled Frostmaster manufactured in California. Three burners placed triangularly around a tree can provide for variance in wind direction. The best performance seemed to be obtained with under-the-tree heating.

A vaporizer is essential for operation with propane gas. Otherwise the system will freeze up as a result of heat taken up in vaporizing the liquid.

Most systems in use are lighted with propane hand torches. Most systems also were designed to yield only 3 to 6 million BTU per acre per hour, whereas it is generally accepted that 9 million BTU are needed under extreme conditions in many orchards. Specific details of several systems can be found in Meister (1967).

Another version of the gas heater is a gas-fueled ceramic block (8 by 6 by 2 inches) yielding only radiant heat in the infrared zone. These heater blocks offer a cheaper way of supplying infrared than do electric bulbs (Sutter, 1962).

Environ-Trol is a pipeline system designed to accommodate both gas burners and water sprinklers. Manufactured in Florida, the Environ-Trol system uses the same pipe network for heating and irrigating, with controlling gas flow to heaters at the tree bases and at another time sending water flowing to sprinklers at the treetops. Scott (1937) proposed methods to prevent corrosion of pipelines and valves in such systems.

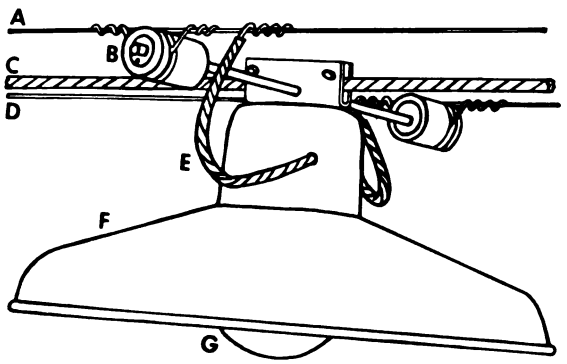

Fig. 10–26. Infrared lamp-reflector-hanger assembly used for orange orchard overtree heating. Legend: (*A*) 110-volt AC wire [−]; (*B*) porcelain insulator; (*C*) strain cable; (*D*) 110-volt AC wire [+]; (*E*) lead-in wire; (*F*) metal reflector; (*G*) 260-watt infrared lamp.

Electrical Heaters

Following the severe advective freeze that struck southern California in 1937, many attempts were made to simplify frost-protection operations and reduce smoke nuisance. The heating system offering promise at the time was very simple in operation, electrical, and therefore absolutely smokeless. Q. E. Bashmore of Covina, California, designed, patented, and marketed a Frost Lite system featuring carbon-filament infrared lamps (Anonymous, 1939).

The lamps in aluminized reflectors (fig. 10–26) were hung on heavy strain cables strung between iron pipe poles set in alternate rows of a citrus orchard. The lamps were suspended 4 to 6 feet above the trees, so that the radiation field from a single lamp covered parts of 12 trees at the rate of 8.5 to 13 kilowatts per hour per acre. The installation was thermostatically controlled so that the lamps would turn on when the temperature dropped to 38° F (Dobie, 1948). Twenty-six such installations were made in southern California, but seven of these were removed by 1947. The two reasons given for the removal were the high cost of electricity and the inadequate protection (Dobie, 1948).

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An appraisal of such installations is easily made by estimating the heat replacement requirements for adequate frost protection and comparing these estimates with a calculation of the amount of heat actually delivered by the infrared lamps. Radiation to a clear sky on a frosty night is estimated to be nearly 1 million BTU/hr/acre, and this loss must be made up to prevent injury to citrus. A severe frost night, on the other hand, may require replacement of about 9 million BTU/hr/acre.

A typical infrared heating installation consisted of one lamp for four trees or twenty-five lamps for an acre of one hundred trees. Since one kilowatt per hour generates 3,412 BTU/hr, the twenty-five 260-watt infrared lamps would have turned 6.5 kilowatts into 22,178 BTU/hr/acre. This was a trifling amount of heat when compared even with the frost night requirements of about one million BTU/hr/acre. Doubling the number of 260-watt lamps would have given a total of only 13 kilowatts producing 44,356 BTU/hr/acre —hardly enough for a single tree under severe cold conditions.

Gordon and Brooks (1940), noting thirteen installations of infrared lamps in southern California, and after observing that they had not given satisfactory frost protection in Florida conducted laboratory experiments in which boxed citrus trees four or five feet tall in a refrigerated room were irradiated with 120-watt infrared lamps. Fruit, leaves, and shoots all froze. Infrared as heat was not produced in sufficient quantity to protect against freezing.

Michigan State College investigators (Anonymous, 1946; Farrall, Sheldon, and Hansen, 1946; Hassler, Hansen, Farrall, 1947, 1948) found that they could protect vegetables against frost with a large metal reflector using electric and oil burning heaters supplying radiation at the rate of 10 watts per square foot. This unit, for 43,560 ft^2 and 3.4 BTU per watt, could deliver about 1.48 million BTU/hr/acre at 100 per cent efficiency, but at 46.5 per cent efficiency this would yield 689,000 BTU/hr/acre. Compared to oil-burning heaters using 25 gallons per acre per hour (3,500,000 BTU), the total heat input from the infrared is small. If radiation alone is considered, the oil heaters could produce about 30 per cent, or 1,050,000 BTU in radiant energy. This is a significant amount more than the reflector radiant-heater systems. However, large, light, horizontal surfaces, as used by one of the electric radiant heaters, would not survive high wind storms, such as are common in southern California. Since the radiant intensity varies inversely as the square of the distance from the receiving surface to the source, the protection with this device at ground level is rather non-uniform unless heaters are close together.

Two methods which will prevent freezing of small trees down to temperatures of 13° F for three quarters of an hour have been described by Yelenosky and Horanic (1969). In one method, an electrostatic field of 2 million volts was generated and broadcast by wires strung a few inches above lemon seedlings. The other method was to connect the high voltage source directly to the tree containers and allow the energy to leave the plant through the leaves. These methods need further development. The high voltages used provide low current losses and possibly economical and automatic frost protection.

Dooryard trees may be benefited during moderate frosts if an ordinary tungsten filament lamp is hung under the green canopy. A 100-watt lamp can supply 340 BTU/hr. If the tree is lightly covered with burlap or similar material, this is often sufficient to prevent freezing.

Irrigation and Sprinkling

If irrigation water is from wells as in Indio, California, the water may be quite warm (69.8° F or 21.0° C). In a citrus orchard, such water may be used for frost protection. The heat given up by the water in cooling from 21° C to 0° C would not be sufficient, when supplied in ordinary practical amounts, to meet the demands of net radiation loss to the sky on a frosty night. However, the heat given up as the water becomes frozen to ice would be about fourfold as great as the heat released in the cooling process. Thus, the application of irrigation water can supply a great deal of heat to an orchard because of the water's high heat capacity, especially when the change of phase occurs and it freezes. In very severe freezes, cultural practices which supply large volumes of water, and greater amounts of heat, as in "flooding" and "basin irrigation," are more effective than regular irrigation when a limited volume of water is run in regular irrigation channels. Heat lost by evaporation tends to offset heat supplied as both sensible heat and as latent heat. The interactions are complex and will be dealt with in more detail later. Excellent protection was afforded by the application of these methods at Indio, California, in the 1958 freeze. They have been used effectively in Arizona for over forty years and

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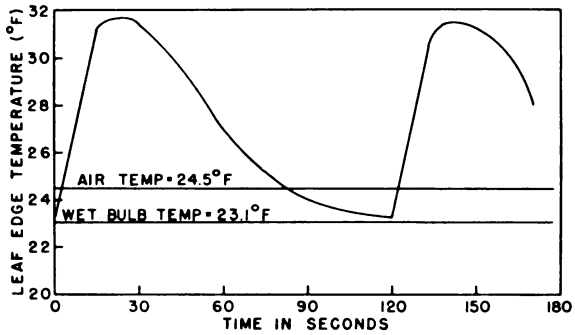

Fig. 10–27. Effect of wind and wet-bulb temperature on the leaf-edge temperature as it approaches the wet-bulb temperature, when drops of water are applied at 120-second intervals. Wind velocity 2.7 mph; leaf parallel to wind (no ice on leaf); green bean leaf in small wind tunnel (no radiation); water applied at 0 and 120 seconds. (From Wheaton and Kidder, 1964.)

gave satisfactory protection during the severe 1962–63 freeze.

The same principles apply when trees are sprinkled. Successful frost protection of nursery trees was obtained by a few operators using the latter method during the 1962–63 freeze in Florida, but it was completely unsuccessful in commercial citrus groves. It is essential in the sprinkling method to add a second drop of water before the first is completely frozen so that heat is continuously supplied as shown in figure 10–27. This method is not considered satisfactory in California because the weight of ice is likely to break the tree. The weight is excessive as a result of the usual very dry air during radiation frosts. Prevention of such breakage by staking would be very costly. In extreme southern Florida, high humidity of the air generally accompanies most frosts and makes sprinkling feasible, whereas elsewhere in Florida it is successful only on young nursery trees. The examples seen showed a general lack of success in the 1962–63 advection freeze because of "freezing-up" of spray nozzles and also probably because of the extremely dry air (dew point of 0° F or less) which tended to cause evaporative cooling of the spray. This has been observed for equivalent dew points in southern California. The very rapid cooling rate induced by the strong wind and uneven coverage due to gustiness also was a cause of failure. But the primary cause of failure was that the evaporative, convective, and radiative cooling were greater than the latent heat released. Thus, sprinkled leaf temperatures were near wet bulb temperature and below ambient air temperature by several degrees.

In California and Arizona, overhead sprinkling is not recommended for citrus because of the hazards of evaporational cooling and limb-breaking loads of ice. Even low-head sprinklers have been found hazardous. Hilgeman (1963) found all leaves with ice on them were killed during the 1963 freeze in Arizona.

Smoke and Man-Made Fog

Pioneer citrus growers in southern California produced smoke by burning wet straw in fire boxes on sleds pulled through the orchard (McAdie, 1901). Smoke was then believed to be the effective factor in orchard protection. However, several kinds of smoke have since been tested by the University of California, and none has raised the ambient air temperature at the ground. During the 1937 freeze in southern California, dense smoke from the oil orchard heaters, tires, wood, and other combustible materials hung over the citrus areas for days and blotted out the sun. It was suggested that the smoke intensified the freeze, which was of many days' duration, because the particle size was too small to absorb the terrestrial infrared, but the right size to absorb the visible rays of the sun, i.e., mostly smaller than 2.19μm (Lee, 1972). According to Stephens and Price (1972) in concentrations of 10^4 to 10^6 particles/ft,^{3} the particle size ranges from 0.3μm to 2.0μm in diameter, while in concentrations of 10^2 to 10^3 particles/ft^3 they range from 5 to 10μm in diameter in orchard heater smoke.

A man-made water fog for frost protection of fruit orchards has been made and successfully tested in a preliminary way by Palmer (1969), working under the auspices of the Boeing Company. Preliminary indications are that the method may have promise under certain conditions. A steam generator is adjusted to produce water droplets 20μ in diameter, which before ejection into the atmosphere are coated with a monomolecular layer of cetyl-alcohol. The liquid water droplet absorbs very strongly in the atmospheric window at 8 to 15μ wavelength. The cetyl-alcohol prevents evaporation, stabilizes the size of the drop, and also acts as a reflective coating against terrestrial radiation.

A second type of water fog is produced by pumping water at moderate pressure in above-ground pipes supplied with microjets. The water streams are fractionated into microdroplets (10 to 25μ in diameter) in sufficient quantity to pro-

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duce a fog. Trials are under way by Mee Industries, Inc. of Altadena, California (Anonymous, 1970). The superior heat absorption of water droplets theoretically promises advantages in this type of fog.

Shades, Covers, and Radiation Shields

The purpose of shades, covers, or radiation shields is the protection of the plant from very low temperatures that result from heat loss from radiation. Such protection is needed at a time when the air is very dry and still. Radiation from terrestrial objects escapes very rapidly to the outer atmosphere of the stratosphere or "sky." Very little back radiation occurs because of lack of sufficient water vapor in the atmosphere to absorb and reradiate the infrared back to earth. The air, if still, does not turn over by eddy convection in the first 50 to 100 feet above the ground and mix with that which has been cooled by contact with the ground. Under these conditions, radiation frost is imminent. One of the means by which heat loss from the ground to the sky can be curtailed is by interposition of a thermal nonconductor between the radiator and receiver. Date palms, *Phoenix dactylifera*, of the Deglet Noor and other varieties in the Coachella Valley of southern California, have been used to shade grapefruit and orange orchards for more than half a century. They have been quite effective, even with temperatures as low as 12° F to 15° F, in preventing radiation frost damage (black frosts), as shown in plate I, *E*, p. 380 (Webber, 1937*a*). This is so effective that shading the plant from part of the sky has prevented frost damage, whereas plants with full exposure suffered heavy frost damage. Camp, in 1940, found citrus growing under pine trees little damaged in a Florida freeze (Batchelor and Webber, 1948).

Even the citrus trees themselves are radiation shields and tend to keep the ground heat from being lost to the sky. This interruption is a result, first, of the leaves being very poor conductors of heat, and, second, of the number of leaves in a line of sight from the ground to the sky (Turrell, Peavy *et al.*, 1967; and Turrell and Austin, 1965).

Cover crops or ground covers are radiation shields. Usually in subtropical areas where citrus is grown they shade the ground surface during the day, reducing the net gain of heat by the soil. Also, less heat is radiated upward from the covered ground surface at night, further reducing its warming influence to the trees above (see chap. 9). Of course, the radiation shielding of grass, alfalfa, mustard, or any of a half dozen additional cover crops also prevents radiation from travelling from the ground to the sky, probably because of their low thermal conductivity. Citrus orchards which have cover crops were found to be colder than bare ground (Young, 1922, 1925). In the mid-November freeze of 1958 in California, the author observed that wind machines working over bare ground gave complete protection for citrus, but when cover crops were present the wind machines were not able to prevent frost damage (Turrell and Austin, 1960*a*). Leyden (1964*a*, 1964*b*) found that citrus under non-tillage with a chemical weed-control regime was warmer and resulted in less frost damage than in cover-cropped citrus.

Nonliving shades, or radiation shields, were used as early as 1912 in the Riverside area of southern California. Shades were made of tobacco cloth stretched on wood frames over several acres of mature citrus trees in the Pomona and Corona districts. Orchards were covered with lath in the San Fernando district and with glass in the Fillmore district. All gave satisfactory protection, but were expensive (Carpenter, 1914). Lathlike lattices made up of tree limbs and woven mats are used in the Sorrento area of Italy to shade mature citrus trees from the cold night sky (pl. I, *F*, p. 380). Similar methods are used in Japan.

Presently, the writer knows of no mature commercial orchards in the United States employing these methods, although they are used in research on citrus. In southern California, a fair amount of usage in commercial orchards is made

Table 10–8

THE REDUCTION IN INFRARED RADIATION FROM AN ELECTRIC HEATER BY COMMON MATERIALS USED AS RADIATION SHIELDS AFTER SHIELDS HAVE COME INTO EQUILIBRIUM WITH THE ENERGY SOURCE*

Material	Thicknesses (No.)	Reduction in Radiation, (Per Cent)
Burlap	1	3.2
Burlap	2	6.6
Plastic (thermometer shield)	1	8.9
Sailcloth	1	6.5
Sailcloth	2	7.3
Sailcloth	4	8.9
Wood (⅝-inch)	1	10.0

*Measured with a Beckman-Whitley Radiometer.

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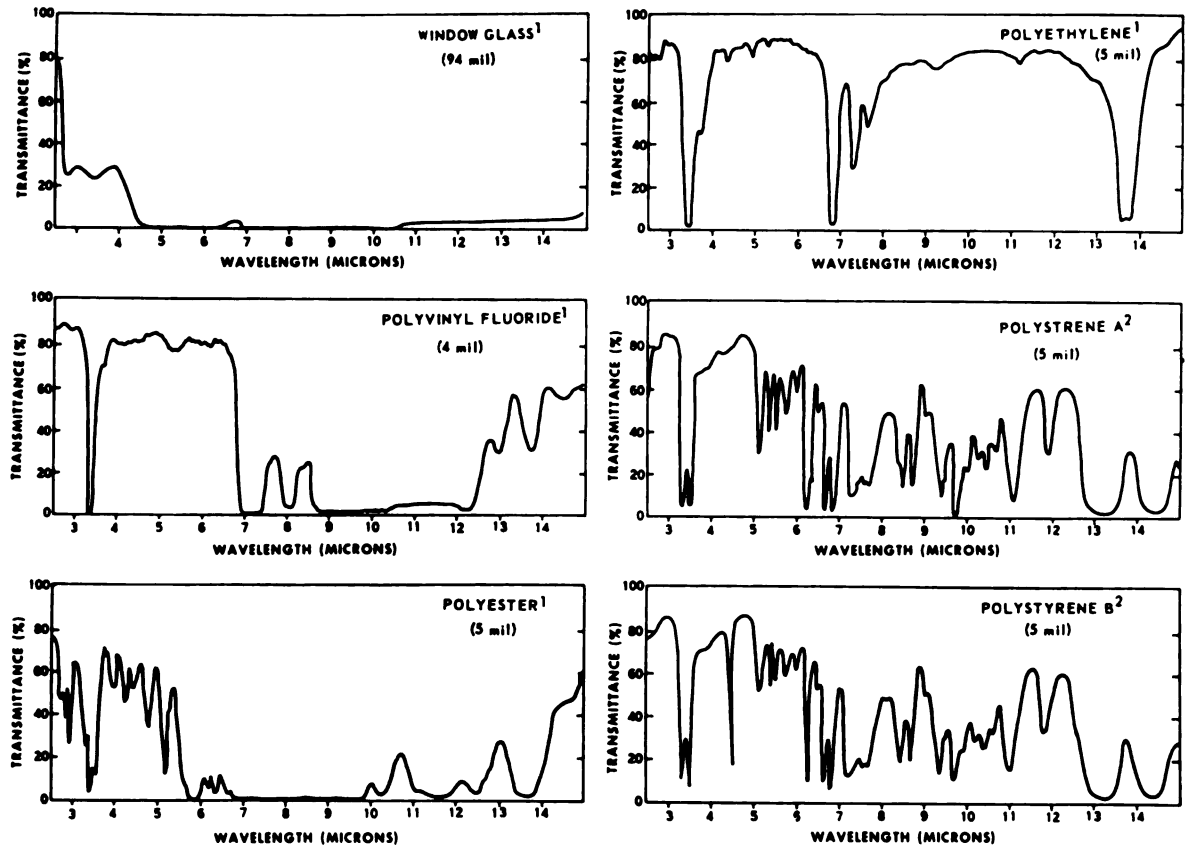

Fig. 10–28. Transmission spectra of window glass and several plastic films. (After Hanson, 1963.)

of burlap covers for small trees up to two years old (Gustafson, 1952). The small trees shown in plate I, *G* (p. 380) had successfully undergone a heavy freeze a few days before this photograph was made.

Tests of the amount of interference with infrared radiation from a General Electric Co. heater on several of the materials mentioned here in connection with uses as radiation shields are shown in table 10–8.

In addition to individual shields for citrus trees, citrus nurseries (Cahoon, Morton, Lee *et al.*, 1963) and experiment stations are employing plastic houses with or without accessory heat for frost protection and other benefits. Plastic houses are replacing glasshouses in many countries. Martin and Batjer (1968) employed Mylar plastic, painted white, for a temperature-controlled greenhouse, for example. The actual infrared spectrum is of interest whenever an application is to be made. The spectra for glass and several common plastic sheets are shown in figure 10–28. The degree of protection of a window glass and several plastic coverings against net radiation loss was measured by Hanson (1963) and reported for polyvinyl-fluoride, polyester, polystyrene, and polyethylene.

The mode of action and effectiveness of various radiation shields are discussed in Appendix III.

Living Windbreaks

Windbreaks are used to break occasional hot summer desert winds, prevailing winds of considerable velocity, or chilling oceanic onshore winds (see chap. 2). While their major function is to reduce dehydration and mechanical damage, windbreaks are used also in some frost-protection programs. They may be essential in starting new orchards when the odds are in favor of hard winter-freeze cycles. Two kinds of windbreaks are in general use: (a) living and (b) nonliving.

Living windbreaks are used more extensively in California than in Florida and still less than in Texas, though they are widely used in the Mediterranean citrus areas. Blue gum (*Eucalyp-*

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tus globulus) has considerable prominence in California as a windbreak. It is often interplanted with the variety *Compacta*, which is used as a filler tree near the ground. In desert areas, tamarisk or desert athel (*Tamarix aphylla*) has been generally successful, and near the coast the Monterey cypress (*Cupressus macrocarpa*) has been replaced by Arizona cypress (*C. Arizonica*) and by the Forbes cypress (*C. Forbeii*).

The nonliving windbreak is made of lumber, mats of limbs, large leaves, heavy fiber mats, or cloth on frames. Such windbreaks are more common in the Mediterranean citrus areas than in the United States. They may be the length of the entire orchard and have heights of 20 to 30 feet or be confined to the size of a small tree. Closely spaced or double lines of heaters placed on the upwind side of an orchard are effective windbreaks.

From the viewpoint of frost protection, living windbreaks might profitably be used on the usually warm hilltops where freezing winds of high velocity in advective freezes that occur every ten years or so would otherwise eradicate citrus hilltop plantings. Shade provided by tall windbreaks protects nearby orchard trees from sunshine after a frosty night, and thus seems to provide better recovery from frost damage (Yates, 1963). In addition, during advection the air in the windbreak-protected orchard is usually one or two degrees warmer than in orchards where there are no windbreaks.

Windbreaks may be disadvantageous during radiation frosts if cold air flowing down the slope is dammed up. Eventually the dammed area is filled with the coldest, nearly motionless air, and then the cold air overflows the windbreak in much the same way that water flows over a dam. In many situations, this difficulty can largely be avoided by judicious orientation of the tree rows and the windbreak. Wind machines can effectively protect the orchard inside the windbreak-dammed area, pushing out the cold air, permitting the relatively warm air of the inversion layer to drop down and mix with the cold air at low levels among the trees in the orchard. While fuel for orchard heaters can be saved by slowing the wind with a windbreak, and, on occasion, can save the loss of an entire grove during an advective freeze, competition from living windbreaks within the orchard can cost the grower an estimated 10 per cent of the profit each year. Despite the top trimming and root cutting necessary to reduce fertilizer, water, and light competition, some growers

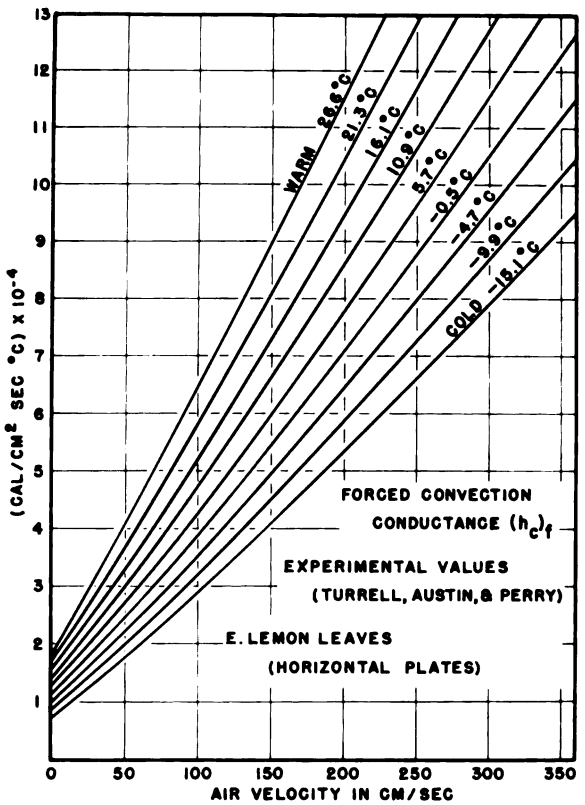

Fig. 10–29. Forced convection conductance $(h_c)_f$, experimental values (Turrell, Perry, Brooks *et al.*, 1963) for Eureka lemon leaves (horizontal plates).

prefer to gamble with possible severe tree damage and loss of the crop on the average of every ten to fourteen years, and some wind scar damage to fruit most years rather than use windbreaks.

Windbreaks will be considered here only from the standpoint of freeze protection. A freeze has been defined as a low air temperature, damaging to plants, in which a large mass of cold air moves into an agricultural area with considerable velocity (see p. 339). This definition appears not to have been adopted by meteorologists, but it has great specificity for subtropical agriculture. North winds during the winter season were recorded as hazardous to citrus as early as 1871 when 20 to 30 mph winds severely damaged citrus in southern California (Blair, 1909). Blair later determined that out of 118 days of "northers," 25 lasted one day; 40, two days; 27, three days; 17, four days; and nine of them more than four days. Blair also noted that in the Sacramento Valley they occurred on an average of 43.6 days a year or 3.6 days per month. Their occurrence is, however, in some degree cyclic, since the severe

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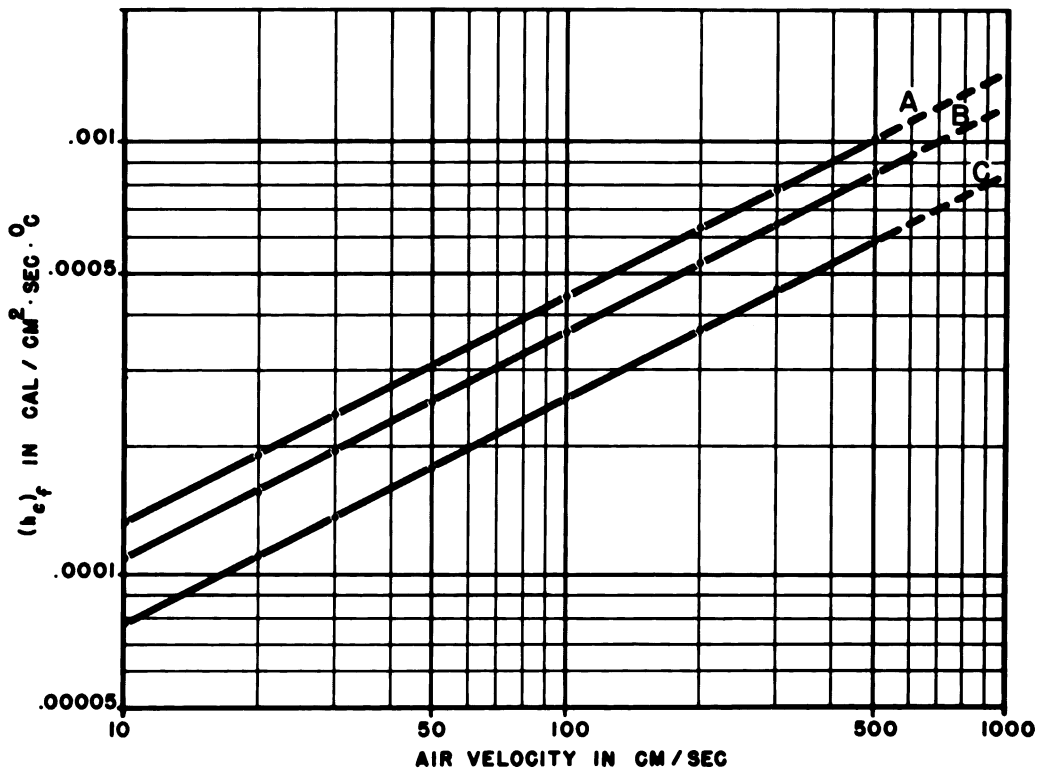

Fig. 10–30. Forced convection conductance $(h_c)_f$ variation with increase in wind velocity for oranges (spheres). Calculated using the Ebaugh equation (Leggett and Sutton, 1951). Diameters of oranges: A = 2, B = 3, C = 6 inches.

"freezes" which occur every ten to fourteen years in southern California, Florida, and Texas are a result of their action. In California, the extreme dryness of these winds has long been recognized (Blair, 1909; Carpenter, 1914, 1919; Durrenberger, 1956; Hoge, 1919; McAdie, 1912; Reed and Bartholomew, 1930; Smith, 1924; Vaile, 1924; Young, 1929; Vaile 1938*b;* Turrell, Perry, Brooks *et al.,* 1964), as well as in Texas (Young, 1963*a;* Peynado, Young, and Cooper, 1963) and Florida (Cooper, 1963*a*). The driest and strongest wind recorded in California was in December, 1891, when the trees glowed with phosphorescence and "balls of fire leaped from tree to tree" because of the buildup of static electrical charges on the trees (Young, 1938*b*). During a norther, relative humidities may run between 5 to 20 per cent and dew points may hover near 0° F. Both in California and Florida, dew points of –30° F were read in the 1962 freeze.

There are two effects of wind. The plant and its environment are cooled rapidly to the temperature of the air, and water is extracted from both of them rapidly. If there is a steady source of heat under these conditions, the greater the air velocity, the greater the rate of heat loss from the orchard. This is shown for lemon leaves in figure 10–29 and for orange fruit in figure 10–30. Even when the air is cold if the temperature is near the dewpoint there is linear increase in transpiration rates with increase in air velocity. Fruit open to the air through stomata even though they are partially plugged with wax, and twigs open permanently to the atmosphere through lenticels, and also transpire heavily through leaf scars and buds. Transpiration of leaves at night is not affected much by wind velocity. The citrus leaf is a well-waxed container which is mostly closed to external air at night. A negative correlation may develop because of stomatal closure resulting from shaking of the leaves (Gregory, Milthorpe, Pearse *et al.,* 1950; Turrell, Austin and Perry, 1962*a*).

There are also usually two effects of wind confined to the plant. In the United States, the winter wind to be feared is the dry north wind, called a "norther" (or "Santa Ana" in southern California). When the dew point and therefore the water vapor pressure in the air is very low, the influence of increasing wind velocity may be

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less, but transpiration in leaves, fruit, and twigs in increasing order will increase greatly as the vapor pressure or relative humidity of the air is lowered in the same way that free evaporation from an open pan of water is increased (see Appendix III, p. 517).

It was estimated that more than 50 per cent of the damage in the severe California freeze of 1913 was a result of desiccation (Carpenter, 1914). Cooper (1963*a*) reported the desiccated appearance of leaves and the high damage to twigs in Florida in the 1962 freeze. Vasil'yev (1961) contends that in Russia winter desiccation is one of the major factors in the frost killing of plants.

The second effect that results from very dry air is that of very strong cooling by (1) evaporation from the plant, and (2) by greater terrestrial radiation to the sky. Wheaton and Kidder (1964) in a study on the effect of evaporation on frost protection concluded that evaporation "can reduce the temperature of a wet or ice covered object below air temperature" and that "the minimum temperature to which a surface can be cooled by evaporation is the wet bulb (or ice bulb) temperature." As has already been noted, this was a very low figure in the 1962 freeze. The addition of wind, of course, increases the quantity of heat lost by evaporation. Miller (1963*a*, 1963*b*), working in southern California during the 1962 freeze when the dew point was –8° F and airdrift 2 to 4 mph, found that the temperature of wet leaves of orange trees was as much as 6° F lower than air temperature. At a dew point of –8° F, the ice bulb temperature, the minimum attainable by evaporation is 18° F for a dry bulb temperature of 25° F and 11° F for a dry bulb of 10° F. To be safe under dry air conditions, one must determine the wet bulb temperature and operate sprinklers as long as this temperature is below freezing. See Appendix III (pp. 517 to 520).

Moving air that is extremely dry may cause the evaporation from moist soil surfaces and roots resulting in the desiccation of foliage (Bohning and Lusanandana, 1952). The freezing dry air desiccates citrus leaves (Hilgeman and Howland, 1956). According to Waynick (1928) complete tree defoliation by desiccating winds reduced the average Valencia orange fruit size by two packinghouse sizes, and winds of 4 per cent relative humidity stopped growth irreversibly. The second characteristic of dry air is treated elsewhere in this chapter. Radiation to the sky is greatly increased by dry air and will be discussed further in detail under radiation frost (p. 506).

Theoretical considerations (Appendix III, p. 517) clearly indicate reduction in windspeed will greatly reduce transpiration and consequent desiccation of the tree. Windbreaks of eucalyptus and other trees have long been used and quite successfully. To combat the velocity effect of the wind, over 450 miles of windbreaks protect the area near Fontana in southern California (Batchelor and Webber, 1948). Obviously, the dryness component would not be greatly modified by this method at night unless the ground were wet (Mertz, 1924), but apparently slowing of the wind is sufficient aid to permit good tree yields. This is borne out by the hygrothermograph record showing 10 per cent higher relative humidities on the lee side of a windbreak (Batchelor and Web-

Table 10–9
COMPARISON OF WIND VELOCITIES IN THE OPEN AND BEHIND WINDBREAKS

	Wind Velocity (Mph)		
	Average Hourly	Average Hourly Maximum	Maximum for Period
November 18, 1925			
Station in open	12	15	27
Station 165 feet behind windbreak*	5.5	6.5	15
Decrease due to windbreak (%)	54	57	45
December 8 to 10, 1925			
Station in open	18	22	29
Station 310 feet behind windbreak*	8	9	....
Decrease due to windbreak (%)	56	59	55

Source: Batchelor and Webber (1948).

* Windbreak made up of one-half eucalyptus about 95 feet high, and one-half Monterey cypress about 70 feet high. Both the eucalyptus and the cypress were about thirty years old.

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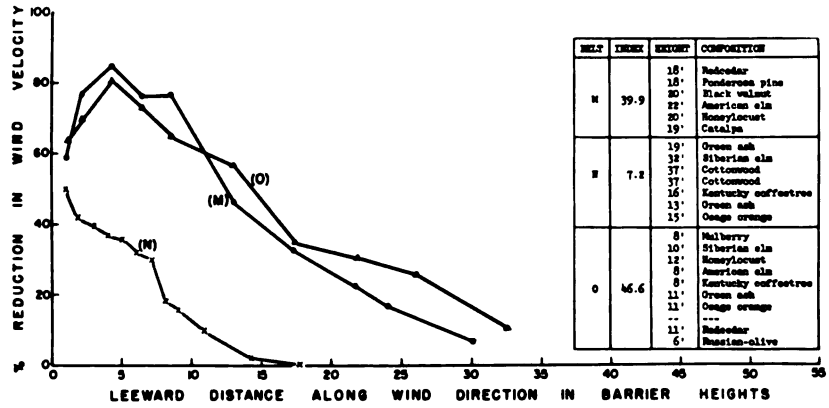

Fig. 10–31. Wind velocity reduction curves for four-foot height to the leeward of windbreaks made up of 6, 7 or 10 rows of trees of species and heights shown in table. (From Woodruff *et al.*, 1963.)

ber, 1948). Blanchard (1934) in a study on the effect of windbreaks obtained a yield of 97 fruit per tree without a windbreak and 710 fruit per tree with a windbreak. Northers of high wind velocity bring freezes to Texas and Florida with about the same frequency as to California, but freeze damages were greater in Texas in 1962, partly because little use had been made of windbreaks. Both the wide fan of near level ground of the Rio Grande Valley, Texas, and the tops of low rolling hills of Florida were especially vulnerable.

The effectiveness of windbreaks as barriers against wind is variable. It is dependent on the kind and age of the tree, the velocity of the wind both parallel to the ground surface and vertical to it, its thickness and the number of windbreaks and their deployment in the area. A thirty-year-old eucalyptus and cypress windbreak was found by Young to retard winds averaging 12 to 18 mph (maximum 27–29 mph) by between 45 and 56 per cent (table 10–9). Wind velocity of 45 mph was reduced to 15 mph or 66 per cent, in the completely protected area of an orange orchard (Reed and Bartholomew, 1930). According to these authors, windbreaks give a zone of complete protection five to six times their height.

As with other physical systems, data obtained from experiments with scale models can be plotted in dimensionless groups and employed to show the action of full-scale equipment (Langhaar, 1951). This has been done by Langhaar (1951), Woodruff (1954), and Woodruff and cooperators (1952, 1959), who established correlations between wind tunnel and atmospheric profiles. They found the profiles nearly the same for models and field trials for both single and successive barriers. Shape, height, and density each affected a lowering of the surface velocity of the wind, but the flow patterns were similar regardless of velocity. Absolute protection was dependent on velocity, but the percentage reduction in velocity was constant. Trees gave better protection than a solid object, providing the degree

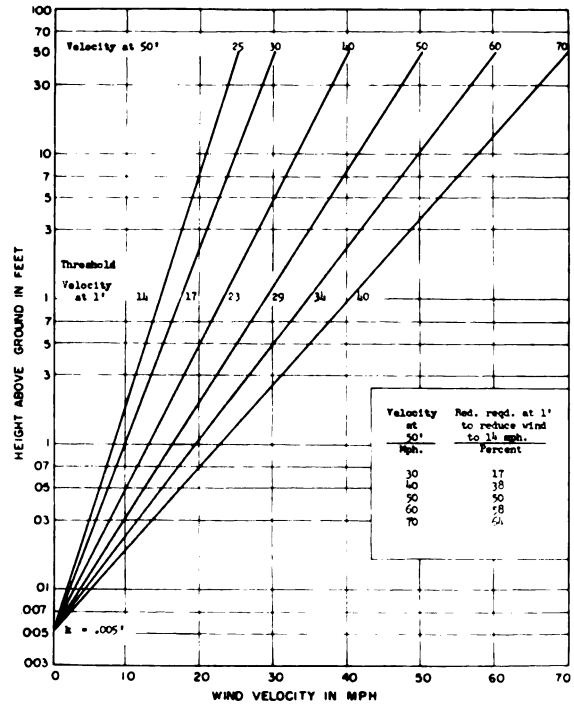
HEIGHT ABOVE GROUND IN FEET
WIND VELOCITY IN MPH
Velocity at 50'
Threshold Velocity at 1'
Velocity at 50' Mph. | Red. reqd. at 1' to reduce wind to 14 mph. Percent
30 | 17
50 | 38
60 | 50
70 | 58
k = .005'

Fig. 10–32. The relationship between wind velocity and height above the ground in feet, at two levels for a smooth, bare, fallow surface. (From Woodruff *et al.*, 1963.)

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Fig. 10–33. Windbreaks on playa of the Santa Clara River near Ventura, California.

of protection required was not too high, because of the more gentle air flow pattern immediately behind the trees. The openness of trees is also desirable for downhill air flow during radiation frosts, etc. Woodruff, Fryrear, and Lyles (1963) showed that it was possible to obtain a very effective barrier with two or three rows of trees. Examination of figure 10–31 shows that the *m* and *o* belts reduce the wind velocity 50 per cent, or to about 14 barrier heights. Figure 10–32 shows the logarithmic drag effect of smooth, bare, fallow ground on wind velocity at various heights. Some typical and effective windbreaks of southern California of which there are some 5,000 running miles, mostly of blue gum (*Eucalyptus globulus*) are shown in figure 10–33.

Nonliving Windbreaks

Large board fences both solid and interspersed have been used as windbreaks in all citrus areas in the United States, Europe, and the Orient. However, the materials of the country are most often utilized, and limbs or small trees are bound together to make a palisade. In some countries, palm leaves or corn stalks are held together in fence-like structures to protect small trees.

Both walls and fences have been erected as windbreaks for citrus orchards. Like heaters, their maintenance and cost may actually be less than for living windbreaks, but their effective area of protection is perhaps even less than heaters since their effective height is less. Fences and walls are usually constructed of wood, which limits their height to fifteen or twenty feet. A solid wall should be avoided, since low pressure builds up behind the wall, shortening the down-wind protected area. A fence or a wall, through which air can flow and equalize the air pressure on the upwind and downwind sides, has a much greater reach (van Eimern, Karschon, Razumova *et al.*, 1964). Wood or metal posts supporting strips of burlap, sailcloth, plastic, or similar materials can also be used as effective windbreaks.

Insulators and Tree-wraps

Many kinds of materials are applied to individual citrus trees to reduce damage from cold winds. In Japan, for instance, layers of rice straw are bound around the limbs and trunk of a tree. The terminals are topped off with a conical straw hat (pl. I, *H*, p. 380).

Brushing is another method of utilizing natural materials; corn stalks, palm leaves, and other plant materials are stacked over small trees in teepee fashion (fig. 10–34). Such dry plant products are highly insulative thermally (Turrell, Ross, and Iwata, 1969).

In Florida and Texas, the practice of "banking" or throwing up the soil high around a young tree trunk (to the crotch) is a type of individual windbreak. Soil banks are effective in keeping young tree trunks above the freezing point. Yelenosky (1966) stated that wind had no

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Fig. 10–34. Corn stalks placed on small citrus trees to prevent wind damage and radiation damage, Fresno County, California. The process is called "brushing." (Photo courtesy of Robert G. Platt.)

appreciable influence on the temperature underneath soil banks. Such banks are not, however, used in California because of the heavy insect and fungus damage that results. In Florida and Texas, the banks must be removed in the spring and replaced in the fall to avoid insect and fungus damage. The operation of banking, either by hand or by machine, is expensive and inconvenient.

Rohrbaugh (1956), working in Texas, reported two years of successful tests in encasing young tree trunks with manmade insulation. He surrounded a trunk with an asphalt-felt cylinder 12 inches in diameter, filled the space between trunk and cylinder with mineral wool insulation, and tied the wrap in three places with galvanized iron wire (pl. I, *I*, p. 380). He estimated the life of such wraps at six years and gave them the name "permanent bank." Aluminum foil also was tried in place of asphalt-felt. Leyden (1957) used mineral wool banks of 8, 12, and 15 inches in diameter, but found the soil bank warmer. Rohrbaugh and Leyden (1958) measured the slow rate

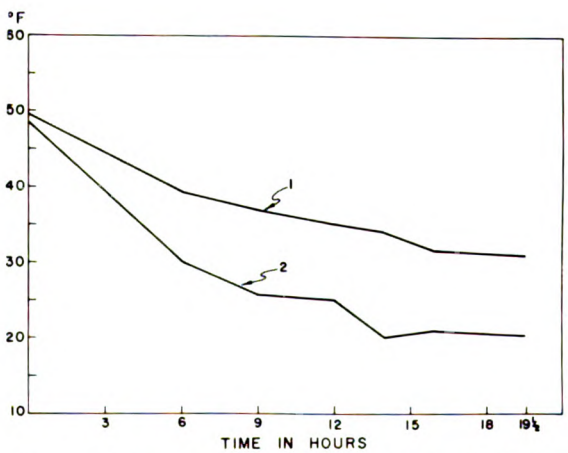

Fig. 10–35. The rate of temperature drop in the bark of a citrus tree with trunk under a rockwool bank (1) compared to that of ambient air (2) inside the cold test chamber. (From Rohrbaugh and Leyden, 1958.)

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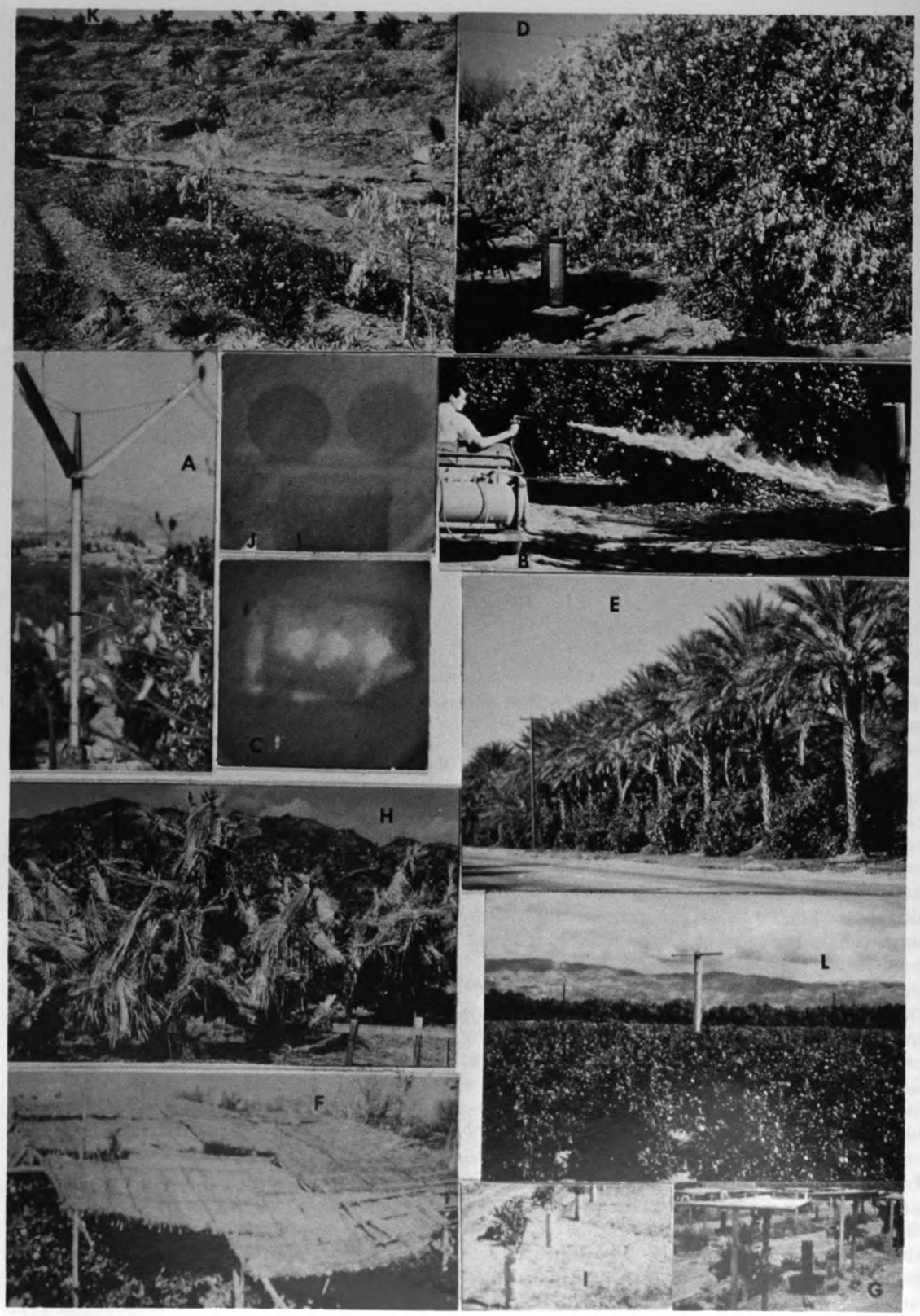

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of temperature loss by a three-year-old grapefruit tree trunk encased in the first kind of permanent bank made by Rohrbaugh. Although the rockwool was wet (which resulted in less insulation effect), after 19.5 hours an 11.8° F difference existed between ambient and bark temperatures, with ambient at 20° F for the last 5½ hours (see fig. 10–35).

Nearly 100 per cent of the trees (over 1,000) that had 4-inch thick glass-wool banks survived a January, 1962, freeze in Texas, whereas only about 50 per cent with 2-inch thick glass-wool banks survived (Leyden and Rohrbaugh, 1963).

Other materials (often supported with chicken wire) tested and found satisfactory include Owens-Corning fiberglass building insulation, polyurethane foam padding, Air-flow Tree Protector (aluminum foil-covered, corrugated cardboard), and Owens-Corning "TWF" fiber glass (Fucik and Hensz, 1966; Young, Fucik, and Hensz, 1967).

In California, the trunks of young trees are covered with tree-wraps, which are often much thinner and lighter in weight than the banks or insulators used in Texas. They are applied primarily to prevent rodents, rabbits, and other animals from eating the tender bark, but they also prevent sunburn, desiccation, windburn, scarring from flying sand, and a certain amount of freeze damage. They are made of old newspapers, corrugated cardboard, fiber glass (Bushman, 1965), balsam wood, polyethylene-coated milk-carton board, or corn stalks.

Insulated or wrapped trees in all locations must be treated to prevent fungus infection. Brown-rot control spray is satisfactory for this purpose. Bordeaux or zinc Bordeaux also can be used, and spraying tops and bottoms of rockwool banks with Heptachlor each spring and fall has been found effective.

No matter how much care is taken in applying wraps, it is necessary to unwrap and inspect trunks for disease, vermin, and frost damage. None of the citrus-growing areas is immune. Some observers have believed that even in California, using very light wraps, the southwest sides of the trees may become too warm, do not get chilled as much as do the north sides, and thus become susceptible to cold injury. Bark is killed and splits, and infection then develops (Rackham, 1965).

The purpose in "banking" or wrapping in Texas and Florida is clearly to save the tree trunk. Although a freeze may cause all the wood above the crotch to be removed, with a healthy trunk as a start a new top may be produced in a short time and fruit production resumed with minimal loss.

Insulating the tree trunk from the air lowers its surface temperature during the day and

Plate I. ***A,*** **Therm Retain wind machine in a citrus orchard, Elsinore, California.** ***B,*** **flame thrower for speeding up lighting of orchard heaters is operated from a gas-driven golf cart which mounts a 15-gallon propane-butane tank on the rear. (Photo courtesy of Rudolph Neja.)** ***C,*** **pair of petroleum coke bricks, side view in darkness, two hours after lighting. Photo taken in infrared by Baird-Atomic Evaporograph. Temperature of brick 1 hour after lighting was between 1,500 and 1,600° F. Note lack of indications of convection heat of flame.** ***D,*** **foliage of Washington navel orange trees killed by strong cold wind-drift from Mount Elsinore in Mid-November, 1958. Radiation from paired heaters kept section of tree closely in view of heaters from freezing.** ***E,*** **grapefruit trees flourishing under Deglet Noor date palms near Indio, California. Although frost protection is afforded, fruit production is reduced in the shaded trees.** ***F,*** **rattan mats used as radiation shields in citrus orchards near Sorrento, Italy. (Photo courtesy of Marvin Miller.)** ***G,*** **young Washington navel orange trees with burlap radiation covers survived the 1962 California freeze when in the lee of large trees. Temperatures were reported as low as 18° F in Redlands, California.** ***H,*** **rice-straw wrapped citrus trees at Okitsu Experiment Station, Japan, afford excellent frost protection. (Photo courtesy of W. P. Bitters.)** ***I,*** **glasswool tree wraps (permanent banks) on young grapefruit trees after the January, 1962 freeze. Photograph taken at the Texas College of Arts and Industries, Weslaco.** ***J,*** **infrared picture photographed with Evaporograph in absolute darkness by the radiation emitted from the object itself. A warm grapefruit (red) having a temperature of 128° F with a maximum per cent radiation of 4.45 μ wavelength is shown at right. A cold grapefruit having a temperatures of 32° F with a maximum per cent radiation of 10.6 μ is shown at left above a stainless steel beaker containing ice water. All are in front of a copper background which appears bluish to yellowish and has a temperature of 102° F with maximum per cent radiation of 9.3 μ. The differences in these maxima make it possible to distinguish between the four objects.** ***K,*** **graded freeze damage with ground level. Heavy grapefruit tree damage at base of hill and decreasing damage upward. The photograph was taken in the mid-November freeze of 1958 on the Corona-Elsinore road in California.** ***L,*** **grapefruit trees protected from the north wind during the January, 1962, freeze at Indio, California, by a small reservoir (not shown) and a wind machine supplying convection for heat and moisture from the reservoir equivalent to 29 return-stack heaters.**

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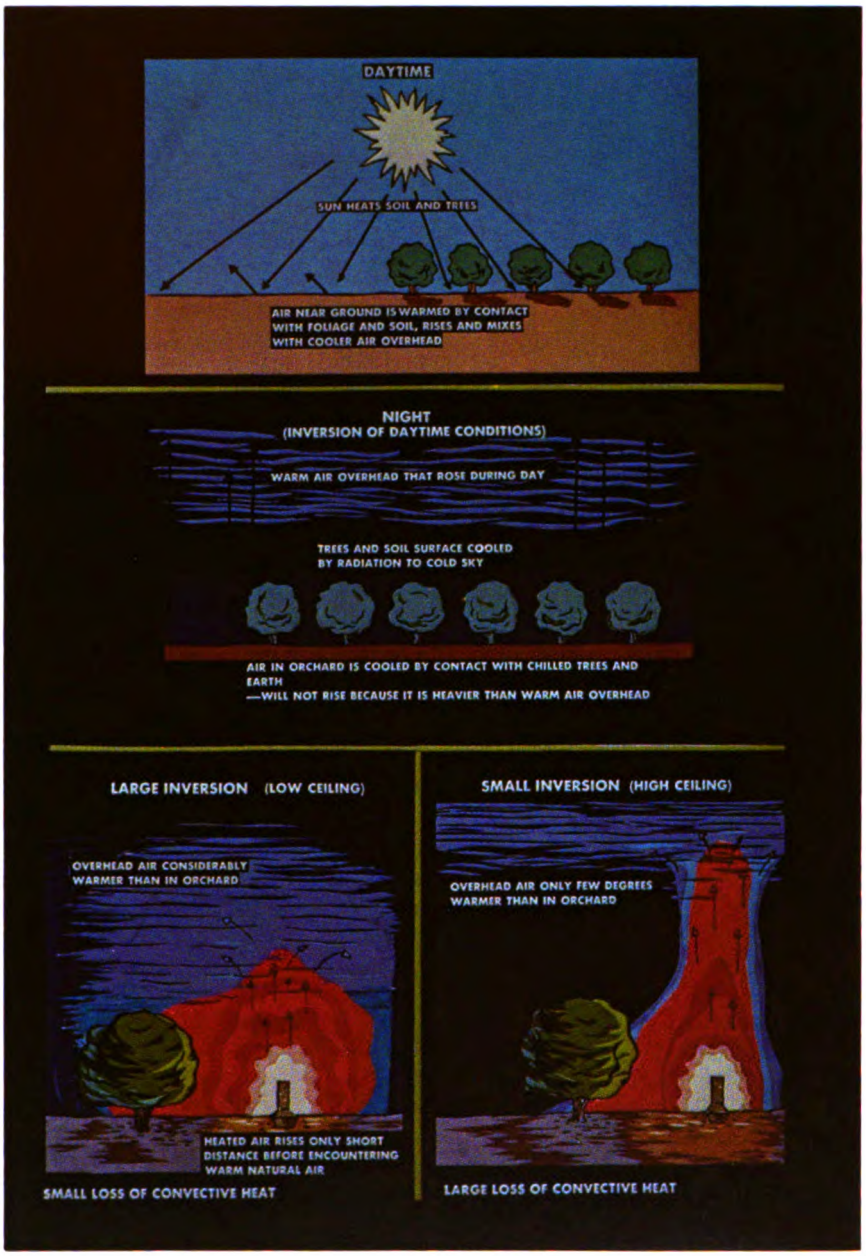
DAYTIME
SUN HEATS SOIL AND TREES
AIR NEAR GROUND IS WARMED BY CONTACT WITH FOLIAGE AND SOIL, RISES AND MIXES WITH COOLER AIR OVERHEAD
NIGHT
(INVERSION OF DAYTIME CONDITIONS)
WARM AIR OVERHEAD THAT ROSE DURING DAY
TREES AND SOIL SURFACE COOLED BY RADIATION TO COLD SKY
AIR IN ORCHARD IS COOLED BY CONTACT WITH CHILLED TREES AND EARTH
—WILL NOT RISE BECAUSE IT IS HEAVIER THAN WARM AIR OVERHEAD
LARGE INVERSION (LOW CEILING)
OVERHEAD AIR CONSIDERABLY WARMER THAN IN ORCHARD
HEATED AIR RISES ONLY SHORT DISTANCE BEFORE ENCOUNTERING WARM NATURAL AIR
SMALL LOSS OF CONVECTIVE HEAT
SMALL INVERSION (HIGH CEILING)
OVERHEAD AIR ONLY FEW DEGREES WARMER THAN IN ORCHARD
LARGE LOSS OF CONVECTIVE HEAT

Plate II. The development of an inversion layer, and use of large and small inversions in heating procedures. (After Kepner, 1950.)

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raises it at night. Subsequent warming of the trunk results from convective heating by the transpiration stream and thermal conduction from the roots and branches. Normal diurnal cycles are shown in figure 10–54 of Part II. Heat travel is slow in fresh wood and for longitudinal flow averages only 0.34 and for transverse flow only 0.24 BTU/ (hr ft²-°F/ft) (Turrell, Austin, McNee, and Park, 1967). Thus, survival of the trunk is dependent upon the insulating quality (thermal conductivity, K) of the tree-wrapping material, its thickness and the duration of low temperatures. Knowledge is not complete, but K values and thermal diffusivities, α, are given in table 10–10 for several materials of density, ρ, and heat capacity, C_p. The amount of insulation of a particular kind needed for a given minimum temperature can be calculated by methods given by Crawford (1964*c*). The single thermal property which is the most significant indicator of merit as a tree trunk insulator under daily transient conditions is the thermal diffusivity (i.e., the capability of diffusing heat under changing temperature regimes). A low diffusivity is desirable for minimizing temperature changes.

The size of wood (diameter) that will be damaged by a given duration of minimum temperatures if unprotected by insulation is shown in figure 10–36. It is assumed that the cambium cells will be killed when a lethal temperature of 19.4° F (–7° C) is attained by the xylem amounting to one half of the radius of the limb. This is a purely arbitrary assumption, since the critical temperature changes with the degree of dormancy, and the rootstock and the scion, but it will give a reasonable estimate. It is based on the practice of estimating the hardness of the tree, or the strength and duration of a freeze by the diameter of the woody branches killed (Young, 1963*a*, 1963*b*, 1963*c*, 1963*d*; Young and Olson, 1963; Young and Peynado, 1962). The proper line may be selected when the initial temperature of the branch, Vo, is –5°, 0°, 6°, 13°, or 20° C, and air temperature, V, is –8° C for the first five upper curves; for the same five initial branch temperatures, Vo, the second five curves as designated are for an air temperature of –27° C; a third group of curves are for an initial trunk temperature of –5° C and air temperatures of V = –9°, –12°, –17° C, as shown.

Air Curtains

The air curtain has met considerable success in the refrigerating and air-conditioning industry. It is a thin wall of high velocity air at the same or lower temperature than ambient, which

Table 10–10
THERMAL PROPERTIES OF VARIOUS MATERIALS

Material	Density (Lb/Ft³)	Heat Capacity (BTU/Lb °F)	Thermal Conductivity (BTU/Hr Ft °F)	Thermal Diffusivity (Ft²/Hr)
Air	0.0752	0.240	0.0149	0.823
Asbestos	36.0	0.195	0.087	0.0124
Cardboard (corrugated)	10.0	0.3	0.037	0.0102
Clay	91.0	0.21	0.739	0.039
Cotton wool	5.0	0.31	0.034	0.075
Cork board	10.0	0.485	0.025	0.0052
Felt wool	20.6	0.3	0.03	0.0048
Glass wool	12.5	0.16	0.023	0.011
Soil (dense peat, 10% H_2O)	13.9	0.33	0.03	0.0065
Soil (organic matter, solid dry)	94.0	0.46	0.145	0.0034
Soil (non quartz, mineral solid)	166.0	0.173	1.7	0.059
Soil, coarse sand	98.3	0.177	0.25	0.0144
Styrofoam	1.8	0.27	0.02	0.0412
Water	62.43	1.004	0.323	0.0052
Wood (oak radial)	38.0–50.0	0.57	0.10–0.12	0.0043–0.0047
Wood (fir, 20% moisture, radial)	26.1	0.65	0.08	0.0048

Source: Crawford (1964*c*).

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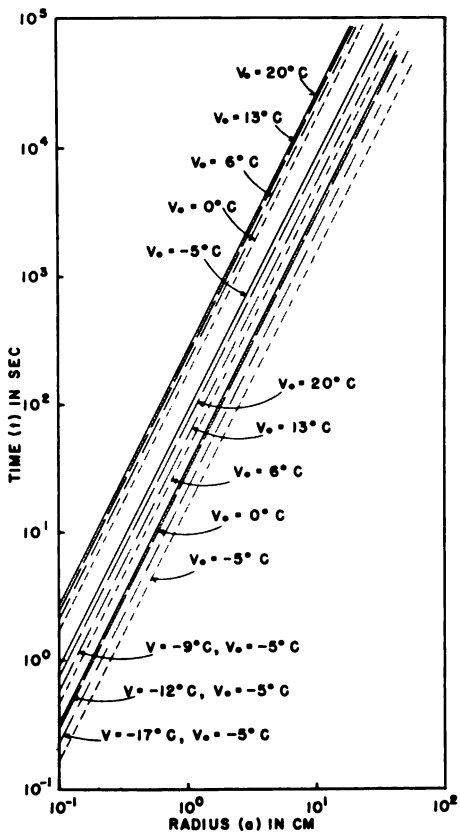

Fig. 10–36. Time (t) in seconds versus outside radius (a) in cm for temperature at a radius of 1/2 (a) to reach an estimated killing temperature of 19.4° F (–7° C), because of radial heat flow. Calculated for a diffusivity of $\alpha = 2.31 \times 10^{-3}$ cm²/sec, and a surface conductance of 8.13×10^{-6} cal cm^{-2} sec^{-1} °C^{-1} where the initial temperature t_{WL} of the branch is suddenly placed in surrounding air at a temperature, t_s.

maintains its integrity over the area of an opening (door) to a walk-in refrigerator, an air conditioned restaurant, or a department store. Such air curtains have not been tested for frost protection.

In park areas with lakes, ponds, or rivers, containing luxuriant plantings of tropical vegetation representing very large capital outlays, water curtains have been proposed. It is envisioned that high pressure pumps will send a thin wall of water 50 to 100 feet in the air at strategic locations upwind of the most susceptible or valuable plantings. No advection freezes have occurred recently enough in southern California to permit the testing of this system.

The hot jet of gasses from the stacks of modern oil-fueled heaters is sufficiently rapid and the volume is sufficiently great that they can be advantageously used as windbreaks. For this rather crude but quite successful modification a single or double line of orchard heaters placed on the upwind side of the orchard is generally recommended. The rapid ascent of very hot gases from the stack orifice form a curtain or wall which reduces the influx of cold air at the orchard level. An advantage of this system is that the warm air is mixed with the invading cold air by eddy convection at higher levels and returned to the orchard some distance downwind. Experience has shown that two rows of closely-packed heaters upwind of a grove of citrus trees are effective barriers against the high velocity winds of an advective freeze. Such a windbreak of heaters does not have many of the disadvantages of living windbreaks, but the protective reach of such a wall is less.

Chemicals

A number of chemicals applied as foliage sprays have been investigated experimentally as protectants against freeze damage. Glycerine, urea, and ethanol were the first chemical sprays observed to lower the frost-killing point (Levitt, 1956, 1962). Polymers of *N*-vinyl-2-pyrrolidone in carriers such as water, oil, oil-in-water emulsion, glycerols, glycols and glycol ethers, and also in carriers patented by Coulter (1962) have given some protection down to 24° F.

Oil favors supercooling (Levitt, 1956); thus oil sprays could be expected to reduce frost damage. The use of oil spray, however, on Washington navel oranges increases the incidence of water-spot, a serious type of peel injury (Klotz, Boyce, Chapman *et al.*, 1949; Riehl and Carman, 1953). Preliminary experiments in a rain chamber by Riehl and Coggins (1964) showed that water-spot is substantially reduced when oil spray is followed by gibberellin A_3. Cooper and Peynado (1958), however, showed that gibberellic acid applied as a foliage spray to Red Blush grapefruit trees removed their dormancy. This finding suggests that there is little hope for protecting against frost damage by the use of oil sprays. In fact, Young, Dean, Peynado *et al.* (1962) showed that winter oil spray reduced the cold hardiness of Red Blush grapefruit trees in Texas.

Maleic hydrazide sprays, because of their inhibitory effects on growth, have held out hopes for increasing frost resistance. Dormancy, a state of suspended growth, has long been associated with the increased hardiness of citrus (Cooper,

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1959; Cooper, Young, and Turrell, 1964; Young and Peynado, 1962). Erickson, Brannaman, Hield *et al.* (1952), working in California, found that the diethanolamine salt of maleic hydrazide retarded growth of citrus. In Texas, Cooper, Taylor, and Maxwell (1955) and Cooper and Peynado (1955) found no induction of dormancy by maleic hydrazide when it was employed as a foliage spray or as an additive to irrigation water. Cooper and Peynado (1955) also found 2,4,5-T slightly inhibited cambial activity and gave a 1° F increase in cold hardiness, but the following growth regulators gave none although other effects were noted: 2,4-D, MH, Dalapon, amino triazole, sodium arsenate, CMU, CIPC, HPA, BTHB, 2-4, 5-TP, MOPA, Sesin, Natrin, and 2,4,6-5′.

Marth (1965) reported the growth retardants Cycocel and B-nine greatly increased the over-wintering survival of cabbage plants, but no results are available for citrus.

The Institute of Viticulture-Erevan, Armenian SSR (Anonymous, 1960) has also tested growth hormones, which in high concentration act as growth inhibitors. The institute has recommended a spray made up of 119 gm of KBr, 109 gm of $CaCl_2$, 75 gm of KNO_3, 1 gm of potassium salt of indoleacetic acid, and 20 ml of isoamyl alcohol made up to 5 liters of water to which 3 to 4 ml of 10 per cent HCl were added. Enhanced frost resistance was reported for apricots, peaches, almonds, grapes, and figs.

A new family of compounds represented by *N*-dimethylaminomaleamic acid and succinanamic acid retard growth (Riddell, Hageman, Anthony *et al.*, 1962), but success with them in enhancing frost resistance has not been reported.

In Florida, Stewart and Leonard (1960), found maleic hydrazide retarded the growth of citrus. Hendershott (1962), also working in Florida, using Valencia oranges on rough lemon rootstock found that growth was inhibited at concentrations of 1,000 to 2,000 ppm for periods of 30 to 60 days after treatment. Wood and leaves were protected against freeze damage down to 20° F to 21° F for about four hours. In California, however, Burns, Garber, and Hield (1962) and Burns, Hench, and Hield (1964) concluded that although maleic hydrazide retarded the growth of young navel orange trees, results were too variable to recommend maleic hydrazide for practical field use in California. Unlike Florida, most years in California cool temperatures in winter assure sufficient dormancy to maintain maximum cold hardiness.

Dimethyl sulphoxide, because of its high penetrating power, has been thought to offer better protective possibilities to large cells or cells with impermeable membranes than glycerol, although glycerol has been considered a better frost-damage deterrent to small cells (Lovelock and Bishop, 1959). Dimethyl sulphoxide is as effective as other neutral solutes of low molecular weight such as methanol, acetamide, and glyceryl monoacetate. Herschler (1961) has found dimethyl sulphoxide increases frost resistance in older trees.

The most promising spray for frost resistance appears to be *N*-decenyl succinic acid. When sprayed on flowering peach, apple, and pear trees, the flowers become frost resistant down to 21.2° F (Kuiper, 1964). *N*-decenyl succinic acid increases permeability of bean root cells eightfold at 86° F. This would prevent the buildup of liquid pressure in subcooling cells as mentioned elsewhere. Theoretically, its action seems to be compatible with the fact that frost-resistant cells show more rapid plasmolysis, having more permeable membranes (Levitt, 1956, 1958), and the fact that mitochondrial membranes in chill-resistant tissues are more flexible and have a higher unsaturated fatty acid content than susceptible tissues (Lyons, Wheaton, and Pratt, 1964; Kuiper, 1969).

Chemical foams sprayed on flower, foliage, and fruit have been used on tomatoes and strawberries, but have not been tried for frost protection on citrus. Working with tomato plants in Canada, Siminovitch *et al.* (Anonymous, 1968) used a protein-base[1] foam 2 to 5 inches thick that had the proper stability, consistency, density, and expansion to last 18 hours, but gradually disintegrated in 48 hours without chemical damage to the plants from the residue. Above the foam, air temperatures were 25° F; below the foam, tissue temperatures were 38° F. In the untreated plots, damage was almost complete, but in the foam-treated plots, there was practically no damage to leaves or fruit. Working in Louisiana, Chesness, Braud, and Hawthorne (1968) reported excellent success with a four-inch thick foam with strawberries. They found the soil surface under the foam was 11° F to 19° F warmer than air temperatures in the open. In Indiana, Eggert (1968), also working with strawberries and foams 2 to 4 inches thick, found minimum temperatures of 17° F in

[1] Produced by Laurentian Concentrates, Ltd., Ottawa, Canada.

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the open and temperatures under the foam of 29° F to 34° F, or 12° F to 17° F warmer. They used three different foaming agents to prepare a 4 per cent water solution: Airocel PK, Airocel PK plus stabilizer, or UX-166-11X plus stabilizer. The latter appeared to be the best formulation; all were produced by one company[2] and all saved more than 48 per cent more blossoms than survived in the controls without foam covering. The foam persisted about twelve hours, but various degrees of toxicity were observed.

HEATING THE ORCHARD

The common radiation freeze or frost occurring on calm, clear nights fortunately is easier to protect against than the less common, and often more damaging, advection or wind freeze and requires a different technique. The contrasting meteorological conditions associated with these two types of freezing situations and the differing protective requirements have been outlined earlier. Also, the various heating methods and types of equipment used for prevention or reduction of freezing injury have been described and evaluated in previous sections. The primary purpose of the following subsections is to outline methods of equipment usage, management considerations, temperature guidelines, common errors, and other relevant details involved in the practical application of principles reviewed elsewhere.

Weather Information

Daily weather information is reported in several forms during the regular frost season in the major United States citrus-growing regions. Weather maps may be obtained from morning and evening newspapers. Local official U. S. Weather Bureau forecasts usually may be obtained from the "box" on the weather page. Radio and television stations give the latest official weather forecast frequently. In California and Arizona, the U. S. Weather Bureau also broadcasts frost forecasts from certain commercial radio stations directly. Frost forecasts also may be obtained from recordings by telephoning specified numbers in some local areas. During the frost season (usually from November 15 to February 29) the Fruit-Frost Service of the U. S. Weather Bureau gives daily minimum temperature forecasts for the coming night. Extended period forecasts are made also for 5-day and 3-day periods. The former are based on the development of surface charts showing positions of highs, lows, and frontal systems supplemented by prognostic charts of the upper air, 500 MB, for 24, 36, 48, and 72 hours.

Orchard Thermometers

A vital instrument in guiding orchard frost-protection operations is the thermometer for measuring air temperature. The standard grower's thermometer is designed to be accurate within one half of a degree Fahrenheit or one fourth of a degree Centigrade. More sophisticated instruments, such as thermographs and hygrographs, are also used by growers to some extent. If these are to register correctly, especially on a clear, calm frosty night, they must be properly shielded from the night sky and a running calibration must

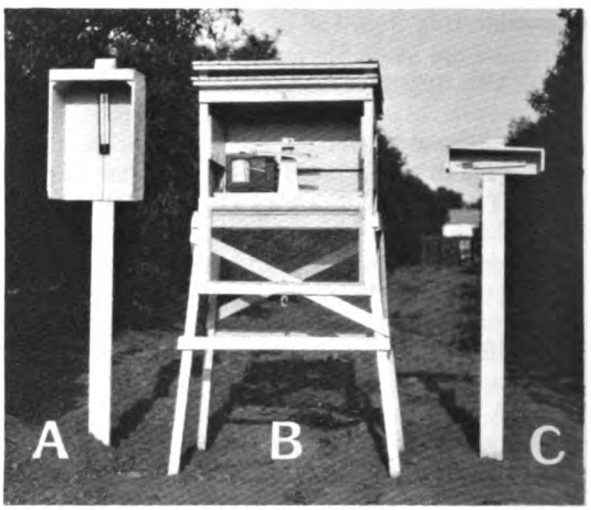

Fig. 10–37. ***A,*** **rough type of shelter for a vertical thermometer, which may be constructed from an apple box attached to a post and firmly anchored to prevent vibration. The bottom and the front of the box is open.** ***B,*** **U. S. Weather Bureau fruit-region instrument shelter, showing exposure of thermometers and the thermograph. Suitable for use only in fall, winter, and spring. Thermograph is checked regularly with a calibrated mercury thermometer.** ***C,*** **instrument shelter for horizontal-mounting minimum thermometer, made with two thin boards about 9 or 10 inches wide and 16 or 18 inches long, placed at right angles to each other, one constituting the back of the shelter and the other providing a cover for the thermometer. All structures are built so that the sensing element will be 5 feet above the ground. Inversion layer temperatures increase from 0.5 to 0.9° F (0.3 to 0.5° C) per foot. The top board of** ***C*** **is hinged to permit setting the thermometer. (From the Floyd Young collection in the library of the University of California, Riverside.)**

[2] Produced by Mearl Corporation, Roselle, New Jersey.

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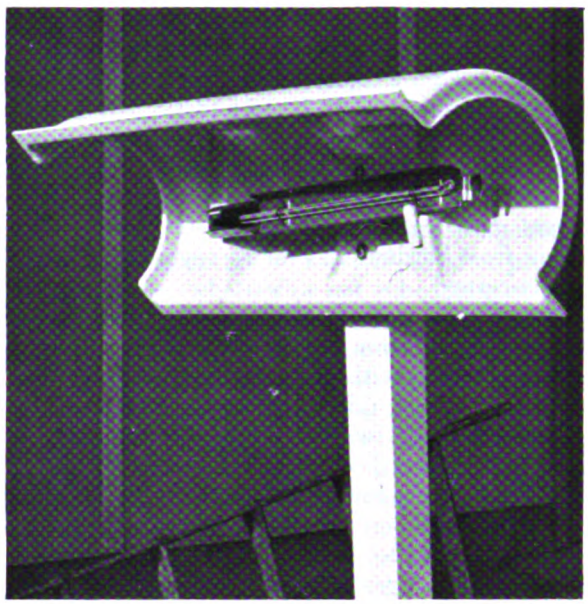

Fig. 10–38. A sturdy, efficient thermometer shelter (radiation-shield) made of molded, highly reflective, impact-resistant, Cycolac brand ABC thermoplastic. Invented by G. M. Byrum, U. S. Fruit Frost Service, Pomona, California. (Photo courtesy of G. M. Byrum.)

Fig. 10–39. Standard U. S. Weather Bureau thermometer shelter of wood construction. Louvered sides provide good air circulation. Access door facing north and painted white reduces cooling at night by radiation. Double roof prevents radiational cooling, and thermometers placed at a standard height 5 feet above the ground obviate the gradient of temperature increase from ground to inversion layer which results from radiational cooling of the air by contact with the ground. (Photo courtesy of Maurice Donnelly.)

be maintained with a standard thermometer. Some of the types of shelters used to shield ordinary mercury or alcohol thermometers, as well as other types of sensors, are shown in figure 10–37. A special type of plastic orchard thermometer shield developed for California citrus growers is shown in figure 10–38. Figure 10–39 illustrates the standard U. S. Weather Bureau shelter used for housing instruments for measuring air temperature and certain other meteorological data in the United States. Tests have shown that accurate thermometers exposed under a double wooden roof register about 1° F (0.55° C) higher on clear, calm nights than comparable instruments shielded by a single roof. (Rogers and Swift, 1970.)

At least two accurate, dependable thermometers properly shielded and placed in strategic locations should be basic equipment in orchards intending to use control methods against freezing temperatures. Larger orchards should have about one permanently-mounted orchard thermometer (of the type illustrated in fig. 10–35) for each five acres, distributed so as to reflect topographic gradients, cold pockets, exposure, etc. These thermometers should be of the type that record minimum temperatures. All should be checked annually for accuracy, and those off more than 1° F (0.5° C) should be discarded.

In Florida, an unshielded thermometer placed on white painted board four to five feet above ground level is recommended for use in determining when to start protective measures (Gerber and Martsolf, 1966), with appropriate downward adjustments in the temperature guidelines. Such unsheltered thermometers will read 1° F to 3° F (0.6° C to 1.7° C) lower than sheltered ones, depending on rate of air movement, moisture content of the air, type of thermometer, and other factors (Young and Harman, 1948).

When to Start Frost-Protection Measures

In Florida, Gerber and Martsolf (1965) recommend the use of unsheltered thermometers to determine when to light heaters for protection of citrus against freezing. They recommend that heaters be lit when the exposed thermometer reaches 26° F (–3.3° C) for protection of all citrus fruits (few lemons are grown in Florida). If only foliage is to be protected, they recommend lighting at 22° F (–5.6° C). Concerning wind machines, Gerber and Martsolf (1965) recommend starting them when air temperatures (sheltered thermometer readings) reach 32° F (0° C) and suggest that cold protection by air mixing should

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Table 10–11
TISSUE TEMPERATURES AT WHICH FREEZING BEGINS FOR CITRUS FRUITS AT VARIOUS STAGES OF MATURITY

Type of Fruit or Tissue	Freezing Begins	
	Temperature (°F)	Temperature (°C)
Green oranges	28.5 to 29.5	–1.9 to –1.4
Half-ripe oranges, grapefruit, and mandarins	28.0 to 29.0	–2.2 to –1.7
Ripe oranges, grapefruit and mandarins	27.0 to 28.0	–2.8 to –2.2
Button lemons (up to ½-inch diameter)	29.5 to 30.5	–1.4 to –0.8
Tree-ripe lemons	29.5 to 30.5	–1.4 to –0.8
Green lemons (larger than ½-inch diameter)	28.5 to 29.5	–1.9 to –1.4
Buds and blossoms	27.0	–2.8

Source: National Weather Fruit-Frost Service (Anonymous, 1971*b*).

be started several degrees before critical temperatures are reached in fruits and leaves.

In California, the U. S. Weather Bureau Fruit-Frost Service in the 1930's carefully worked out the tissue temperatures at which freezing begins. These are listed in table 10–11. In addition, they established air temperature guidelines (as measured by sheltered thermometers) at which frost-protection measures should be started for various types of fruit and weather conditions. Their recommendations for California conditions, as given in a recent publication (Anonymous, 1971), are summarized in adapted form in the following subsections. All temperature data given are based on *properly sheltered thermometers* which indicate *air temperature.*

Oranges, Grapefruit, and Mandarins.—Fruit temperatures are practically always higher than air temperatures when the temperature is falling, but with a stationary temperature for an hour or more the fruit may be cold or even slightly colder than the air. When the air temperature falls rapidly, fruit may be as much as 7° F (3.9° C) warmer than the air.

On cold nights following warm days (highest temperature 60° F [15.6° C] or more with steady temperature fall to the danger point) ripe oranges, grapefruit, or mandarins should be protected at 26° F (–3.3° C) (sheltered thermometer) and green or half-ripe fruit at 27° F (–2.8° C). On cold nights following cool days (highest temperature 59° F [15.0° C] or lower with very slow temperature fall near danger point) ripe orange, grapefruit or mandarins should be protected at 27° F (–2.8° C) (sheltered thermometer) and half-ripe fruit at 27.5° F (–2.5° C).

The above information indicating mandarin *fruits* should be protected at about the same levels as oranges is based on limited data. However, most varieties of mandarin *trees* exhibit more frost hardiness as far as vegetative growth is concerned.

Citrus trees in climates like the Central Valley of California become partially dormant by late November with persistent cool temperatures (see Appendix I, table I–1), and continue in this state during the months of December and January. At this time the fruit has more cold hardiness and can tolerate lower temperatures. By late November, small navels, mandarins, and partially ripe Valencias should be protected at 26° F (–3.3° C). Navels and grapefruit need protection at 25° F (–3.9° C). By mid-February with higher temperatures, trees usually come out of dormancy, and the danger point of the fruit rises one or two degrees Fahrenheit (or 0.5 to 1° C), about the same as the temperatures used for southern California, where dormancy is likely to be of shorter duration.

Lemons.—Fruit temperatures in lemons exposed to the sky will be as low or slightly lower than air temperatures. Lemons sheltered by foliage will generally be at least a degree warmer than those exposed to the sky.

To save all "button" (small) lemons, temperatures should be held at 30° F (–1.1° C) or above.

To save only the larger green lemons (larger than ½-inch in diameter), the sheltered thermometer should be held above 28° F (–2.2° C).

In the Central Valley of California, lemons become more cold resistant during the cooler months beginning late November through early February. During this period, lemons should be protected at 26° F (–3.3° C). By mid-February with higher temperatures, the danger point usually become 2° F (or about 1° C) higher, about the same as the temperatures used for southern California districts.

If ice forms on fruit early in the night, the larger size green lemons may show rind injury even though the temperature does not fall much below 31° F (–0.6° C). Such damage is of infrequent occurence in most California districts. It

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also has been caused by wet snow remaining on the fruit throughout the night.

All Citrus.—In Arizona and to a certain extent in central California, considerably more subcooling (see page 388) occurs than in southern California, and protective measures may start about one degree lower.

Nevertheless, one should keep sheltered thermometers up to 28° F (–2.2° C) after protection is begun, whether or not subcooling occurs.

Damp nights are more dangerous than dry nights with similar temperatures. Citrus fruits begin to freeze at a higher temperature when they are covered with ice than when they are dry. The temperature fall is usually slow and steady on damp nights. On dry nights sudden and rapid drops in temperature are apt to occur, and should be anticipated. If air temperature fluctuates rapidly up and down, due to wind, the average of the high and low points should be taken as an effective temperature.

Use of Heaters

The general atmospheric conditions which prevail where a radiation frost develops under still air conditions is shown in plate II (p. 382). The principal heat exchanges for the daytime diagram (upper) and night (center) are shown in a citrus orchard. Whether a frost night develops depends on the failure of a 10 per cent or more cloud cover developing, or wind rising immediately above the orchard which exceeds 3 to 4 mph, resulting in air mixing. Radiation and convection account for most of the exchanges. According to Newman (1971), solar radiation, about 50 per cent visible and 50 per cent infrared (heat), accounts for 100 per cent of the daylight energy received by the earth (plate II, upper). About 30 per cent of this is reflected to space from clouds, the earth's surface and aerosols that occur naturally or artificially. The solid earth (lithosphere) and aqueous phase (hydrosphere) together absorb 50 per cent while the remaining 20 per cent is absorbed by the atmosphere, that is, by the clouds (water droplets), water vapor, carbon dioxide gas, ozone gas, and aerosols under nonfrost conditions. The 50 per cent received by the solid earth surface (lithosphere + hydrosphere) is reradiated at long wavelengths to the atmosphere, water vapor, clouds, CO_2, O_2 and aerosols, 40 per cent is latent heat loss by evaporation and 10 per cent is sensible heat loss. The 70 per cent absorbed by these atmosphere components is radiated back to space, and the remaining 30 per cent of the absorption supplies kinetic energy having generated winds and driven ocean currents. On a much smaller scale (micro), the absorption of energy (heat) from orchard heaters as invisible infrared radiation by the same (macro-scale) components results in the cooling of the heated air to that of the atmosphere some 50 to 60 feet above the orchard. This forms a warm layer called an inversion or "low ceiling" which is thick (plate II, lower left) when there is a higher relative humidity and the air is very still, i.e., moving in the trees one-third to two-thirds mph. The overhead air is very much warmer than the orchard air, and moves 1 to 2 mph. When the warm layer is thin (plate II, lower right) the relative humidity is low and/or there is relatively more wind movement (2 to 3 mph), a "high ceiling" exists. On the frost night with low ceiling, protection is easier and cheaper.

Efficiency.—It has become clear from experience with orchard heaters that there are two kinds of heat transfer that growers should effectively attempt to use to obtain maximum efficiency. First, as much of the fuel as possible should be converted to radiant heat. Radiant energy will emanate best from any hot solid surface such as a steel smokestack or the surface of a solid-burning fuel such as coal. Heat in such form cannot be blown away by wind until it has been absorbed by the plant. Also the radiation source should be kept as near the plant as possible. The radiation intensity (flux) declines with the square of the distance from the source. Also, the receiving object should be in full "view" of the source so that radiation which travels in straight lines will not reach an unwanted receiver.

Second, when the larger part of the fuel is converted to convective heat (heated and combustion gases) as much of the hot gases in combustion as possible should be made to pass over the surface of the plant. The heat in the air and gases is picked up by leaves, fruit, and branches through contact conduction. Here, wind, natural or artificial, can be effective in distributing the heated air throughout an orchard so that it does not ascend directly to the inversion layer without making contact with the trees. In severe advection freezes the "plumes" of hot gas from two or more lines of heaters on the upwind border of an orchard can be distributed naturally and effectively downwind. By placing heaters along all the borders of orchards where there are wind machines, the back pressure after the jet has passed will bend the plume of hot gases emanating from

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the stacks and suck the heat into the wind machine area of the orchard. The plume is most easily bent when it results from a limited amount of combustion, because the volume-density of the gas is not greatly above that of surrounding air.

Placement.—The following practical discussion of heater placement is adapted from Puffer and Turrell (1967), and is based largely on California experience.

The location of heaters has much influence upon the total amount of radiant heat received by the trees, and upon the uniformity of distribution of the trees. A large number of small fires give better distribution of heat, either radiant or convective, than a fewer number of heaters at higher burning rates.

If one heater is used for every two trees, the most uniform distribution of radiant heat is obtained when the heaters are placed in each row in the orchard. If one heater is placed in the center of the space between each set of four trees, the heaters in one row should be staggered with the next row. Repeat this pattern throughout the orchard. The heaters would have to be moved to one side in drive rows to allow all heaters to be filled. If heaters in every other row only are needed (one heater per four trees), the pattern would still result in equal amounts of radiant heat to all trees.

Placing the heaters in the tree rows (in line with tree trunks) reduces the loss of radiant heat to the sky, but the distribution is not so uniform because the heaters are close to one side of the trees. If every other row is lighted, the trees in the other rows will receive only about one-third as much as the heated rows.

Extra heat is needed on exposed sides of an orchard. As an orchard is heated, the rising hot air draws in cold air from the sides. The air will be colder for ten rows or more in from the edge of the orchard. Border heaters should not be concentrated on the outside of the orchard, but distributed over the first two or three rows in from the edge.

On the upwind edge, where the prevailing air drift enters the orchard, two heaters per tree on the outside and one heater per tree in the first two rows in from the edge should be used. Not more than two heaters per tree on the outside, nor less than one heater per two trees on the outside and the first row in from the outside is recommended.

On the downwind side of the orchard, one heater per tree on the outside is desirable. On the remaining two sides of the orchard, one heater per tree on the outside and first row in from the outside will suffice.

In mass district heating, the border effects are confined mainly to the orchards on the edges of the heated area. If an orchard within the district does not have another heated area reasonably close, it will probably need extra border heaters.

If there are several types of heaters, the hotstack or combustion-chamber type for the border heating is preferable. Border heaters should not be operated at excessive burning rates. It is much better to operate a larger number of heaters at normal burning rates. In the center portion of the orchard, burning rates should be kept as low as possible to give adequate protection, to reduce the amount of cold air drawn in by the updraft over the orchard.

Orchard Size Effects.—In evaluating maximum requirements for frost protection, the grove situation should be appraised for the future date when maximum protection is needed. If an orchard of ten acres in area is isolated or likely to be isolated from other citrus acreages, it will require twice the heat per acre that a 150-acre, nonisolated orchard requires to get the same temperature rise on the same night (Kimball and Young, 1920). This economy of heating of large acreages has been common knowledge for many years, but methods were reexamined on a 3.5 to 5 per cent slope at an elevation of 1,050 to 1,200 feet and reaffirmed on a 600-acre block using twenty-five 9-gallon oil heaters per acre during the 1937 freeze when 30° F (–1.1° C) air temperatures were maintained at 4½ feet, while in an unheated acreage it ranged from 20° F to 24° F (–6.7 to 4.4° C). In a 28-acre isolated orchard, fifty heaters per acre plus border heaters were not enough with the temperatures dropping to 25° F to 29° F (–3.9° and –1.7° C) inside versus 25° F to 21° F (–3.9° C to –6.1° C) outside (Newcomb, 1949). This later study clearly showed the need for better heat control in the orchard. On various nights heaters were lighted, and then more heaters were lighted to maintain the required temperature. Soon the temperature was over-hot and the heaters extinguished, only to be relighted as the temperature again dropped to dangerous levels.

Use of Wind Machines

The following discussion of the practical use of wind machines is adapted from Puffer and Turrell (1967) and is based largely on California

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experience. Recent experience has proved that wind machines can protect citrus down to 22° F (–5.6° C), if the machines have enough horsepower per acre to do the job and if the orchard is in the right condition to withstand low temperatures.

Wind machines with sufficient horsepower move the air at 4 mph and are most effective in still air, during frosts with moderate to large inversions. During a freeze, the air is usually dry, wind movement is better than 4 mph, and there is small inversion. Even with small inversions, wind machines have helped. For example, one small orchard with a small inversion had a wind machine with sufficient horsepower per acre. Temperatures outside the orchard were as low as 18° F. When the wind machine was started early, there was complete protection. In another orchard under similar conditions, where the wind machine was started late, damage was severe.

When to Use Wind Machines.—If fruit and twigs are cooler than air, wind machines are helpful. This is usually the case in younger orchards. On rare occasions, when there is no inversion layer and no outside source of heat such as heaters or running water, and the air is colder than the fruit, wind machines would be harmful and should not be used.

If the temperature inversion plus the air temperature is below 22° F (–5.6° C), a wind machine will be helpful, but it will not protect unless it is used with heaters or running water. For example, if the temperature inversion is 5° F (–2.8° C) and the air temperature is 15° F (–9.4° C), the total is less than 22° F or –5.6° C, ignoring negative values (i.e., 20° F or –6.6° C), and wind machines will not provide protection. These temperatures prevail when the orchard is healthy and not stressed for moisture, and the soil including the surface is moist. If the soil surface is dry or there is a cover-crop damage will be more severe.

Area Protection and Spacing.—In estimating area for a single machine one must take into account the fact that the air usually will blow only one-third as far upward as it will downward. Air from wind machines blowing at 4 mph protects not more than 300 feet crossdrift.

Wind machines with 15 bhp should be spaced 300 feet by 450 feet. Wind machines with 90 bhp should be spaced 600 by 800 feet. (The 450 feet and 800 feet are along the line of drift.)

Starting Temperature.—The temperature at which to start wind machines depends upon the bhp of the machine and the predicted low temperature. If temperatures not lower than 25° to 26° F (–3.9° to 3.3° C) are predicted, machines should be started at 32° F (0° C).

If lower temperatures are predicted, low-horsepower machines (less than 7 bhp per acre) should be started at 35° F (1.7° C) and high horsepower machines (above 7 bhp per acre) at 32° F (0° C). If in doubt, start the machines at 35° F (1.7° C) on nights when low temperatures are predicted.

When to Shut Off Wind Machines.—Machines should run until the fruit is dry and air temperatures reach 32° F (0° C). Usually this is one to two hours after sunrise. In severe frosts, running the machines well past sunrise can save some fruit that have been frozen solid.

Use in Sleetstorms and Foggy Weather.—A wind machine should not be run in sleet or foggy weather unless it has a metal propeller and the exhaust can be turned so that it blows on the propeller. Otherwise, ice forms on the propeller, puts it out of balance, and may cause damage to the motor and even to the tower. Do not start a wind machine until after a sleetstorm. Protection will be needed only rarely on foggy nights.

Use of Wind Machines and Heaters Combined.—Wind machines used in combination with uniformly distributed heaters provide a response greater than the sum of normal responses when either heaters or wind machines are used alone. Within the area of disturbance, air mixing caused by a wind machine tends to make convective heat from the heaters more useful than if heaters are used alone. A 90-bhp machine, plus fifteen heaters per acre, is 20 to 30 per cent better than the sum of individual responses.

Heaters must still do a part of the frost-protection job, even if wind machines are employed. For areas outside the influence of wind machines, such as the corners in a square grove or exposed borders, high radiant output heaters are important. If a wind machine with adequate bhp per acre is used during nights with radiation frosts, there probably will be no need for heaters on the majority of nights except in areas of an orchard unprotected by the machine.

In California, frost protection by individually fueled heaters alone has become increasingly costly because of the labor needed. In general, wind machines reduce the number of such heaters needed to about one-third and heater hours of operation to about one-sixth, with consequent savings in labor requirements.

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A wind machine plus fifteen heaters per acre is generally recommended. In California, estimates in 1967 suggested that this distribution was 39 per cent cheaper than fifty heaters per acre for medium winters, even when overhead costs for each system were included, and 53 per cent cheaper for severe winters. The costs are about the same for mild winters. The mild winters were estimated at 10 hours and medium winters at 50 hours with large inversions. The severe winter was considered to be 100 hours, which included 50 hours of small inversions.

If heaters are used on nights when low temperatures are predicted, the slowing down of the temperature drop by the wind machine provides time to light the heaters as they are needed.

When used with wind machines, heaters should be distributed uniformly in the grove and lighted on the upwind side first. No heaters should be placed within 30 to 50 feet of the base of the wind machine. There should be no double heaters or banking of heaters within the grove. Strong rising hot air from a bank of heaters acts as a wall to the blast from a wind machine and turns it out of the orchard. Heaters can be banked on the borders of the grove. Rising hot air at the border will help maintain the beneficial effects from wind machines in the orchard.

The microclimatological conditions prevailing during radiation frosts or minor freezes which make use of orchard heaters or wind machines necessary, particularly in the gentle, rolling country of southern California, are illustrated in plate II (p. 382). Under still air conditions during daytime, the plants, soil, and lower-surface air (biosphere) are warmed. At night, the plant-soil-lower-surface air becomes cold, whereas the upper-surface air remains warm (50 to 150 feet above the ground during a large inversion) or less warm (150 to 250 feet above ground for a small inversion). Seventy to 90 per cent of the convection heat from the orchard heater fills the space from the inversion layer down to the soil surface. The effectiveness of a wind machine depends on bringing air in the inversion layer into the tree zone, and the heated air from heaters when they are operated with wind machines.

Handling and Storage of Fuels.—Four forms of competitive fuels have been used for frost protection of citrus orchards: solid, liquid, gaseous, and electrical. No attempts have been made to apply metallic or atomic fuels to frost protection so far as the writer is aware. Each type is more or less better adapted to use in a given locality. Choice revolves around availability, price, storage ability, convenience in handling, and heat content per unit. Pine wood, even if permitted by the State Air Pollution Control Board, would be too high in price to use for frost protection in southern California. Solid fuels such as coke and coal, likewise, have had to yield to cheaper and more readily available fuel oil.

Some approximate current (1972) prices of common fuels per 1,000 BTU's in southern California are: No. 2 oil, $0.00091, at 12.5 cents per gallon; propane gas, $0.00153 at 14 cents per gallon; natural gas (burner plus metal shield), $0.0008 at 8 cents per 100 ft^3; petroleum coke, $0.007; wax candle, $0.005; chopped rubber, $0.002 (Anonymous, 1967).

In general, fuel for frost protection must be stored. One gallon of diesel or orchard heating oil of 24° to 36° Baumé (preferably 28°) equals 1.33 gallons of butane-propane gas, 14 pounds of dry pine wood, 16 pounds of dry oak, 9 to 10 pounds of carbon, 10 to 11 pounds of coal briquettes, 8 to 9 pounds of petroleum coke, and 37 kilowatt-hours of electricity (Schoonover, Hodgson, and Young, 1930). A "standby charge" is levied by electrical companies to provide for extra loads of electricity needed by wind machines and electrical heaters during frosty nights. In citrus districts of the United States, natural gas supplies so far have not been sufficient to meet peak loads during severe cold periods. While natural gas is a storable commodity, no attempts have been made to store it for frost protection.

There must be enough fuel on hand in the orchard to keep fires going the entire duration of the damaging temperatures for three nights if full protection is to be obtained. (Radiation frosts, it will be recalled, are of one night duration; advection freezes generally last two or more successive nights.) On a per acre basis one should have on hand in the orchard ready for use every cold night: for oranges, 400 to 450 gallons in oil heaters; for lemons, 600 gallons in oil heaters; and for reserve, 1,200 pounds of fuel stored nearby in the orchard. Refilling should be done after each ignition. The physical characteristics and heats of combustion of some orchard-heater fuels were given earlier in tables 10–6 and 10–7 (pp. 366 and 367), together with the amounts of some of the other sources of heat in the orchard.

Reserve storage for oil should be provided in tanks above or below ground near the orchard. Their volume should total two or three times the heater capacity. Tanks can be riveted,

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corrugated galvanized-iron, electrically-welded steel, or concrete reinforced with steel. Oil for pipeline systems should be stored in concrete, because reaction between the zinc of the galvanized layer of metal tanks and the oil produces a soap which clogs pumps and valves. While a minimum of 1,000 gallons per acre may be stored for distillation heaters (30 to 50 gallons per heater), 1,500 to 2,000 gallons per acre is the minimum required for pipeline-heater systems. Some growers, particularly those with orchards having heavy soils, prefer to distribute the oil in smaller tanks about their own orchards to prevent long hauls over wet ground.

Cooperative storage is popular in southern California. In several districts, ninety per cent of the growers who used heaters belong to storage associations. Most of these growers also store fuel in their orchards. The size of storage associations vary. One of a dozen of the smaller associations has a membership of 69 growers and a small capacity storage for 455,000 gallons. Larger storage associations of about 150 members have capacities of 1,250,000 to 1,750,000 gallons. Oil is normally purchased in the summer when the price is usually lower (Adams, 1952).

In the United States, hauling of oil from central storage to groves for storage or filling of heaters is usually done with a truck of 1½-ton capacity, mounting an 800-gallon tank. Under unfavorable conditions, heaters have to be refilled with pails, which may be carried a distance of one or two rows. Four men can distribute about 4,000 gallons of oil a day, covering eight to fifteen acres.

Lighting torches of the usual type (see fig. 10–20, p. 358) consist of a 6-quart can and a spout, with a wick and a copper or brass wire gauze screen (which prevents explosions) in the base of the spout. Fuels for these torches, consisting of equal parts of gasoline and kerosene, should be made in advance. Torch fuel should be on hand and stored in tight 5-gallon, 10-gallon, or 15-gallon containers in the orchard. Torches should be filled using only electric torches, never by the light of an open flame.

Fuel for flamethrowers consists of eight parts kerosene and five parts regular gasoline by volume. The standard tank is 25-gallon capacity.

Propane torches are available for lighting heaters. Automatic lighting for oil-fueled orchard heaters are in the demonstration stage of development by two or three different companies. Sinclair Oil Company markets an electric-initiated automatic lighting system for its solid fuel blocks. Automatic lighting for gas has been developed, but does not seem to be marketed primarily because of the limited number of gas systems in use.

Errors in Practical Orchard Heating

Regardless of the amount invested in heating equipment, actual protection of the crop depends upon the efficiency of the manager in preparing for freezing temperatures and carrying out the heating operation. Some common deficiencies are listed in the following sections.

Insufficient Equipment.—Many growers equip their orchards for average rather than extreme conditions. Many types of equipment costs are listed on the basis of average rather than extreme conditions. It should be recalled that as much as 9 million *effective* BTU's per acre per hour may be needed for extreme conditions. In recent advection freezes in the United States (1962, 1968, and 1969), extensive fruit and tree losses were the result of an insufficient number of fires. A common mistake was the omission of border heaters. This extra protection provides against changes in wind direction.

Inadequate Knowledge of Temperatures.—Growers who have too few thermometers, inaccurate thermometers, or improperly installed thermometers will both waste fuel and lose fruit through freezing because of inadequate knowledge of temperatures. Thermometers should be checked annually. The U. S. Weather Bureau Fruit-Frost Service provides this service without charge in most areas using frost-protection methods. Thermometers should be mounted and shielded as recommended. They cannot be found quickly on a cold, dark night if hung in a tree. The coldest part of the night is just before sunrise. If heaters are turned off at this time, smaller fruit will freeze. Heaters can be turned off when a check thermometer in an unheated area indicates air temperatures around 28° F (–2.2° C).

Torches Improperly Prepared and Used.—Crops have been lost because of an inability to light heaters with torches stored from the previous season and not refilled according to Schoonover and Hodgson (1925). The gasoline evaporates from the mixture, leaving only kerosene, which is unsatisfactory for firing. Torches should be freshly filled each season with the proper mixture and then tested before they are needed.

Inadequate Personal Safety.—One of the principal hazards in orchard heating arises from lighting torches which may backfire and explode because they are not in good condition. The

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screen in the tube should be in place and in good repair. This prevents flames from reaching into the tank of the lighter. Never poke a hole in the screen to gain greater flow of oil.

Keep torches clean and always have an extra torch with safety screen intact, and filled with the proper mixture of gasoline and kerosene.

Oil-soaked clothing is another real danger to men involved in orchard heating. Spilling oil on clothes must be avoided. It is possible to treat work clothes so as to render them practically fireproof by soaking them in a solution of one pound of *ammonium sulfanate* (NOT the nitrogenous fertilizer, ammonium sulfate) in one gallon of water and then drying them. No clothing is fireproof, however, if it is saturated with oil.

Heaters Improperly Assembled and Regulated.—Orchard heaters often are difficult to light and will not burn properly when the bowl covers are not on tight. Frequently, heaters go out even if lighted, which is a result of poor placement of the downdraft tube or plate. Heaters should be placed so as to carry the pilot flame toward the center of the heater and keep it concentrated on the surface of the oil as the oil level drops in the bowl. Regulating tall- and medium-stack heaters too soon after lighting will cause them to go out, as will filling them too full of oil. Cleaning heaters too thoroughly makes them like new heaters that have never been lit previously, and therefore difficult to start. On very cold nights such heaters may be nearly impossible to light. Stack covers should be kept on tight to keep out rain. Water may cause frothing of the oil and sometimes result in an explosion. Return-stack heaters are exceptions, however, because they will evaporate the water.

Heaters sitting in snow or ice are slow to ignite. Unless special considerations are given to methods of quickly lighting a few heaters, freezing may occur on a windy night before heaters can be lighted. Any delay caused by icing of parts so that they must be thawed or sticking of parts that are fresh-painted or bent out of shape can be extremely serious.

COLD WET WEATHER, HEAT TRANSFER, AND RIND DAMAGE

In addition to damage to citrus fruit tissues caused directly by freezing injury of cells, various conditions involving cold wet weather have an impact on tissue temperatures during freezing weather. Such conditions may cause superficial injuries or blemishes of the rind without involving temperatures low enough to result in significant cell injury by freezing alone. Cold weather (near freezing) conditions involving snow, sleet, hail, cold fogs, dew, rains, and light frost all occur with varying frequency in most of the major citrus-growing areas of the subtropical zone. The impact of these and associated weather conditions on heat transfer and on formation of free-water films on fruit surfaces, including their relationship to rind injury, is discussed in the following sections.

Snow

When upper air is chilled below the freezing point of water and meets a front of warm moisture-laden air (supersaturated), the water crystallizes out in the form of snow. Snow may be very dry and light or contain considerable amounts of moisture. Although snow is of infrequent occurrence in areas where citrus is grown, it occasionally creates problems. Breakage of trees from the heavy weight of snow caused greater damage than the California freeze in 1949 (Johnston, 1949).

During daylight a snow covering is disadvantageous, since it keeps sunlit tree parts colder than when they are not covered. Sunlight cannot heat the peel because the reflectivity of fresh snow to visible or near infrared radiation is high (80 to 90 per cent), while its thermal conductivity when dry is very low ($K = 0.18 \times 10^{-3}$ cal/cm² sec (°C/cm), especially when the density is very low also ($\rho = 0.1$ gm/cm³). The peels of citrus fruits on the average are five and one-half times as conductive as dry snow ($K \cong 0.995 \times 10^{-3}$); thus a snow cover may be protective at night. The emissivity of snow is about the same as a black body, so that it is an extremely good radiator. It acts as an insulator against radiative loss of heat to cold dry skies, however, because of its poor thermal conductivity. For the same reason, snow will protect against even a very cold air drift. However, if the air becomes warm and the snow melts slightly, the density will increase ($\rho \cong 0.3$). Then the conductivity (K) for snow and citrus peel will be about the same, and there is no advantage to a snow covering. Difficulties are encountered when the process of melting continues. The thermal conductivity of the snow will become increasingly greater than for the peel until the liquid phase of snow is reached. When snow density and conductivity are both very high ($\rho = 0.9$ and $K = 5.36 \times 10^{-3}$), thermal

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conductivity is more than five times greater for snow than for peel. Therefore, it is important to remove melted snow coverings, especially on ripe fruit. In this connection, forced convection by wind machines in early morning gives rapid drying and is an excellent "water-spot" preventative.

The properties of water make it a strong stressing agent when on the surface of citrus fruit. Aside from other effects, surface water can increase the rate of heat gain of fruit in daylight if the evaporative power of the air is low, and increase the rate of heat loss at night. Absorption of water into the punctures, splits, and cracks of the peel cuticle causes "water-spot." This disorder opens the peel to the more serious fungus disorder "water-rot." These and related damaging rind disorders will be discussed in more detail in the section on fog (p. 396).

Sleet

When rain falls from a warm upper-air stratum through a stratum of freezing air nearer the ground, it undergoes a change of phase and sleet is produced. Occasionally, as in Texas in 1951 and California in 1957, citrus is subjected to such a storm. As with snow, the soil and plants are shielded from a very cold sky by clouds. Thus, while a sleet storm is in progress, danger of freeze damage is relatively small. Heaters may be used to melt the sleet as it collects. Wind machines can be used effectively after the storm to dry the fruit. During a storm, wind machine propellers may collect ice, sleet, and snow unless an exhaust or other means is used for de-icing the propeller. The entire machine will then be damaged by the unbalance which it develops. It is desirable to remove water caused by sleet from the fruit surface just as with melted snow. Not infrequently within twelve to twenty-four hours of the passing of such storms, the air becomes extremely clear, dry, cold, and calm, permitting the development of a radiation frost. Citrus fruit should be dry on entering such a period because (1) increased thermal conductivity of the water coating can cause quicker freezing of the fruit (Lucas, 1953, 1954; Young, 1941), and (2) pitting of the peel may occur. Such pitting consists of small red spots that develop in the peel and become more pronounced when the fruit is washed. The beneficial effect of running wind machines late in the morning after a sleet storm at Ventura, California, is shown in figure 10–40.

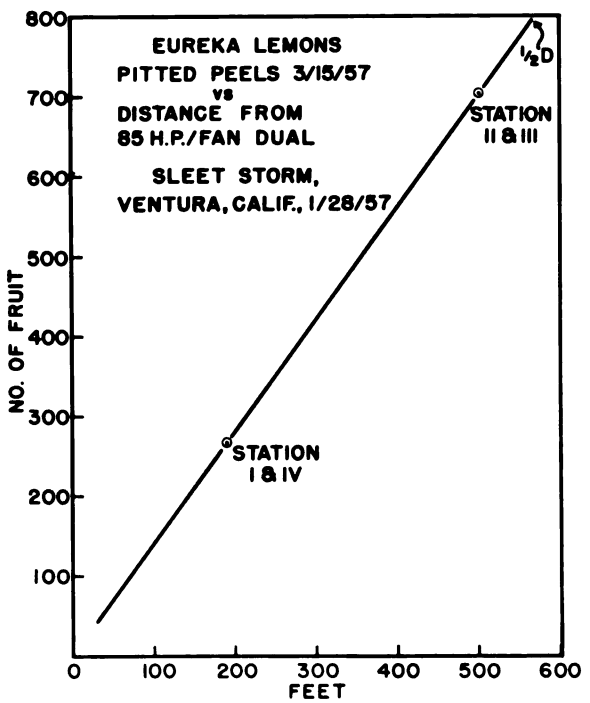

Fig. 10–40. The relation between number of lemons with pink spots three weeks after a sleet storm at two distances from a wind machine. The early morning running of the wind machine reduced the amount of damage to peel from more than 700 fruit per sample outside its range to 280 fruit per sample within its range (Turrell *et al.*, 1957). Red speckling is probably caused by germination of *Alternaria* and *Colletotrichum* spores on the wet surface (Fawcett, 1936).

Frost

Unlike sleet, the change of phase of water vapor to produce frost takes place on the fruit, leaves, and other solid bodies rather than in the atmosphere. If the dew point is 32° F, heat will be released by water vapor condensing from the air onto these surfaces, which are at 32° F or lower. Since 595 calories of heat are produced per gram of water condensed, there is a retardation of the rate of temperature fall on the surfaces as the vapor condenses in addition to the 80 calories yielded on freezing, and in the air itself there is usually a break in the rate of nocturnal-temperature fall as the water vapor in the air gives up its heat at the freezing point. The frost coating itself should be expected to do no more damage to the interior of the fruit than snow, and no more damage to the peel than melted snow. This should not be minimized, however, because the thermal emissivity of hoar frost is 98.5 per cent, and, although it is white to the eye, it is the closest to an absolute black body of any substance yet investigated (Jakob, 1949). Hence, it will lose heat

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more rapidly by radiation. Water, however, on the thawed cellular surfaces probably causes greater injury to the previously frozen cells than a dry atmosphere. Levitt (1957) found that the percentage of partially hardened cells of cabbage petioles that were killed by immersion in water after thawing increased with the length of time they were immersed.

Fog

Clouds at ground level are termed fog. If fog lies a few hundred feet above the ground in central California, it is termed "high fog," although meteorologically it is a stratus cloud. Fogs are common in southern California, and they may be formed in six or more ways in this locality. Ordinarily, fog is formed when an air mass 90 per cent or more saturated with water vapor, is cooled by another air mass. Other factors may bring about the required cooling so that the atmospheric water vapor is condensed into droplets in sufficient concentration to reduce visibility to less than one-half mile, which is required by the definition.

Persistent inversion fogs called "tule-fogs" of two or more weeks duration occasionally occur in winter in the San Joaquin Valley of central California when a high pressure system exists in the Great Basin. A subsidence inversion is set up above the valley floor, which entraps moist maritime air. The dry air above permits rapid radiation cooling at night so that fog is built downward. Under such conditions, trees may remain wet and cool day and night for a protracted period, perhaps a month (Turrell, Orlando, and Austin, 1964). Mature citrus fruit becomes turgid, oil from the oil glands may ooze on to the fruit surface, causing extensive cell injury and pitting between the oil glands, a disorder known as oleocellosis or rind-oil spot (Klotz, 1961). Practically all of the grapefruit and some Washington navel oranges in San Joaquin Valley were affected in the 1963–64 winter (Turrell, Orlando *et al.*, 1964). Because mature citrus fruit contain considerable amounts of water-binding materials such as pectins, sugars, and celluloses, all of which have a relatively large number of hydroxyl groups, they become very turgid when there is excessive moisture available through the ground-root route. Fruit volume is increased (see fig. 10–41; also chap. 9, fig. 9–15, p. 303) and the cuticle may crack from internal pressure and absorption of water take place through the air-peel-surface route (Reed, 1930; Fawcett, Klotz, and Haas, 1933). Under these conditions, oil is pressed from the oil glands through excessive (greater than the normal 5 per cent) diurnal expansion and contraction described for lemons by the above authors and Furr and Taylor (1939).

"Water-spot" was serious disorder of navel oranges from 1936 to 1949. Webber (1937*a*) reported spots of similar appearance on the surface of rind as a result of frost. Hawkins, Taylor, and Barger *et al.* (1949) proved the connection between the liberation of rind-oil and oil-spot during their experiments on artificially freezing lemon trees. Fawcett (1936) in extensive studies showed that the liberated oil kills the cells in the epidermis, hypodermis, and cortex in a few seconds. Turrell, Orlando *et al.* (1964) confirmed

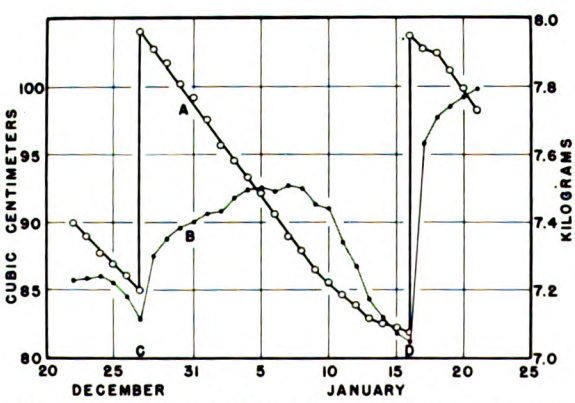

Fig. 10–41. Changes in fruit volume of a fruit on a potted lemon tree in response to changes in soil-moisture content. *A*, weight of pot and plant in kilograms; *B*, volume of fruit in cubic centimeters; *C* and *D*, irrigation intervals. (After Furr and Taylor, 1939.)

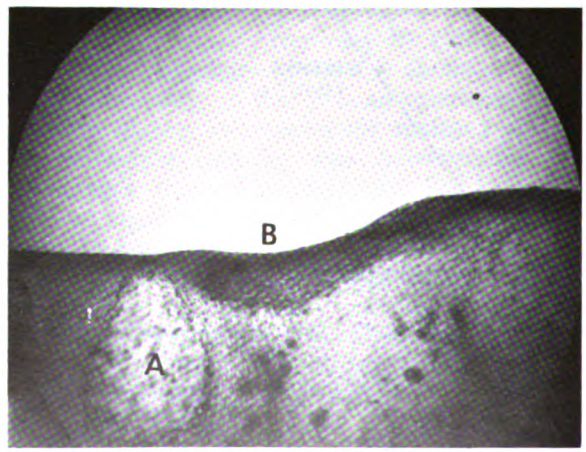

Fig. 10–42. Photomicrograph through outer peel of grapefruit collected in Tulare County, January, 1964, showing oleocelosis. Free-hand section stained with Sudan IV. Oil damaged tissue (*B*) is on right side of oil gland (*A*).

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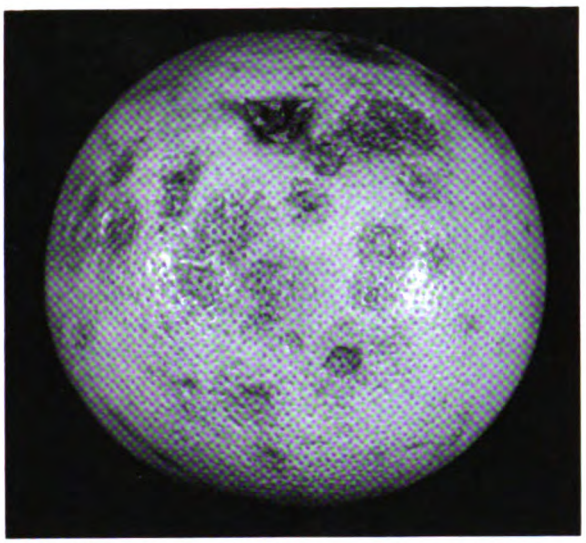

Fig. 10–43. Grapefruit after storage in plastic bag in a refrigerated room at 34° F for three months. The collapsed peel surface areas around oil glands are similar to the rind-oil spot produced in the field. Other grapefruit developed similar symptoms after storage at 50° F for four weeks.

this as a result of "tule-fogs." The type of damage discussed is shown in figures 10–42 and 10–43.

Irrigation should be withheld as soon as such fog is predicted. Wind machines may be used during the warmest part of the day to dry fruit surfaces. Cultural practices in the orchard where contact with fruit would occur and cause spurting of oil should be avoided. Whitewash has been recommended as a corrective, but Webber (1937*a*) after the 1936 freeze observed that reduction in growth and defoliation resulted. He recommended that this practice be abolished.

Entrance of water through peel surface may result from freezing and thawing of fruit which causes the cuticle of the peel and the first three or four layers of the cortex to break loose from the albedo at the crystal bearing-layer (see figs. 10–44 and 10–45). This break opens the hydrophyllic tissues of the inside of the peel and exposes them to penetration by water and to infection by fungi. Vasil'yev (1961) quoted Goppert as saying great harm is done to living tissues by repeated freezing and thawing. He stated that *Euphorbia lathyris* chilled to –10° C or –12° C lived, whereas they died when frozen six times at –4° C.

Ice, Dew, and Rain

Klotz (1961) observed that the peel of citrus fruit is injured when water freezes on it. Ice, when it forms on a fruit surface, is a strong stressing agent, not only from the mechanical standpoint, but because of its physical characteristics. Wet ice at 0° C has an emissivity of 0.97, smooth ice, 0.966, and rough crystals, 0.985, all of which are greater than the emissivity of citrus peel. Thus

Fig. 10–44. Photomicrograph of whole epicarp and hypoderm using polarized light. Tissues were stripped from a refrozen Eureka lemon fruit. Photo from hypodermis side shows hypodermal walls as white lines (double refractive, isotropic, *A*) and calcium oxalate crystals as white, nearly round plates (double refractive, isotropic, *B*) in the hypodermis and nonrefractive stomata (not shown). Crystals may serve as nuclei for ice formation.

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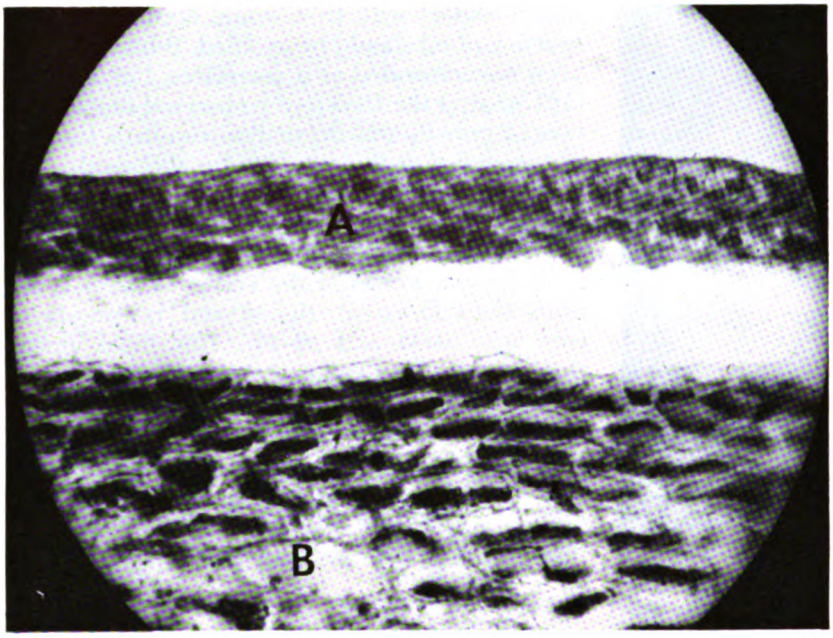

Fig. 10–45. Photomicrograph of section of peel of refrozen Eureka lemon fruit showing splitting of epicarp and hypodermis, *A* from the mesocarp, *B*.

at night ice-covered fruits are better infrared radiators, whereas in daylight they are better reflectors of visible radiation.

It has already been pointed out that the thermal conductivity coefficient for ice is about four and one-half times larger than for citrus peel. At night, ice-encased fruit will cool faster than dry fruit, and during daylight it may not warm as fast because of the high reflectivity of the ice coating in the visible region. Not only is peel injured by ice freezing on it, but unless the fruit surface is dried, water from melting ice is absorbed through abrasions and cracks, in the peel surface although not through the stomata. Should icing occur often or be followed frequently by formation of dew, or should heavy rains follow, the peel may become affected with "water-spot," the physiological disorder already described in which large, translucent water-soaked areas develop in the peel. This disorder is more serious in Washington navel oranges than in Valencias or grapefruit, because navels mature in southern California during the period of winter rains. Johnston (1949), for example, observed that damage to navel oranges in 1949 resulting from snow, ice, and rain was greater than the 1949 freeze damage. Water-soaked areas of fruit that have dried out are deceptive because they may appear normal at picking time. If picked and shipped, greater expenses are involved, because of the accelerated infection (logarithmic) and physiological breakdown of more fruit unless a drying period of sufficient length has occurred so that a depressed, hard, dry darkened spot is developed, preventing invasion of the water-rot fungi which would otherwise ultimately follow. Water-spot incidence is greater in oil-sprayed fruit. Recently, however, it has been shown that gibberellin sprays will control water-spot (Riehl and Coggins. 1964).

HAIL INJURY

Hailstorms are uncommon in the citrus-growing areas of California since they usually accompany temperate zone thunderstorms in locations downwind from continental interior mountain ranges. In Africa, Argentina, Florida, Italy, Spain, Turkey and many other citrus areas, hail may cause severe damage on occasion.

Examples of severe hail damage occurred in mid-December of 1967 and 1968 in California. Intense rainstorms in the San Joaquin Valley metamorphosed into severe hailstorms, with stones of one-half to three-quarters of an inch in diameter, followed by sleet and snow. Leaves on citrus trees were ripped to shreds, and exposed fruit were bruised, causing a liberation of oil from the oil glands onto the peel surface. The citrus oil thus released causes a green-spotting of lemons if they are soon separated from the tree, but, as with oranges, the spots turn brown if the fruit

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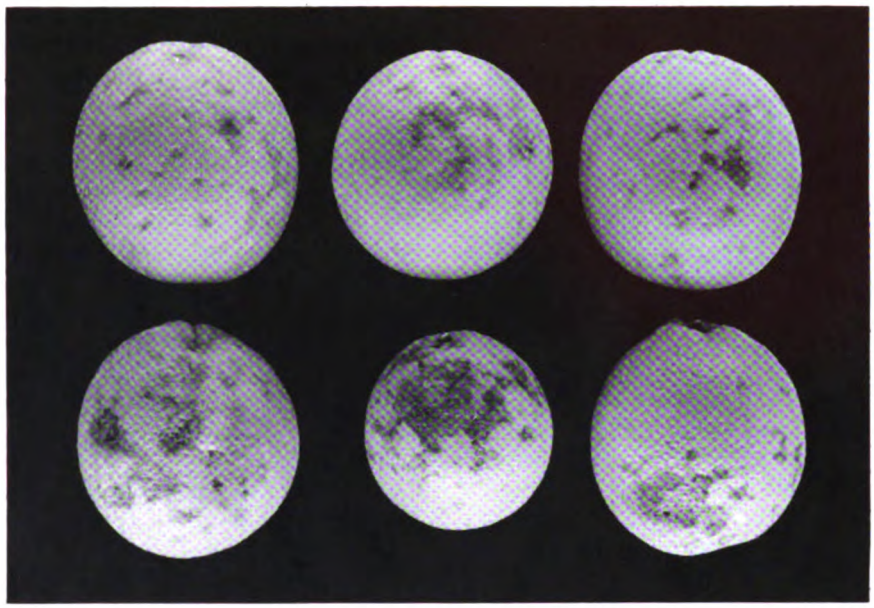

Fig. 10–46. Washington navel oranges damaged by hail in storm of December 19, 1968, at Visalia, California. (Photo courtesy of Robert G. Platt.)

remains on the tree. Such spots are the result of death and collapse of cells of the epicarp, hypoderm, and outer mesocarp outside the oil-gland apparatus (Turrell, Orlando *et al.*, 1964). The peel surface then sinks between the oil glands, allowing them to stand out prominently over the surface of the affected areas. The disorder (fig. 10–46) is known as oleocellosis or rind-oil spot, and was recognized by Fawcett (1936) as resulting from hail in California and Brazil.

The storms in 1967 and 1968, although out of the general range of hailstorm areas (the Great Plains of the United States, the Pampas of Argentina, and the river basins of central Europe and northern India), were typical in that they accompanied a cold front and developed with intensely severe electrical thunderstorms, downwind from the mountains, in late afternoon and early evening. There were also strong gusty winds of short duration.

Foster and Bates (1956) have worked out a hail-size forecasting technique. This is an important aid to agriculture because the degree of damage by hail is a function of the size and density of the hailstones and velocity of the wind. Models have been made of the growth of hailstones. Clearly it is necessary for a stone nucleus to come in contact with considerable moisture at subfreezing temperatures. One model proposes that small stones drop from the top layer of the storm through a moist layer, then are caught up and recycled until they become too large for the updraft. Another model suggests simple juggling within a persistent updraft for a sufficiently long time. Hitschfeld and Stander (1967) state that a stone 1 cm in diameter requires a temperature difference of more than 12° C between clouds and ambient air. Larger stones require larger temperature differences.

Neyman, Scott, Wells *et al.* (1968) suggested that ground-based cloud seeding with silver iodide may either increase or decrease precipitation. Silver iodide smoke from ground-based generators, however, is used in Switzerland, Spain, and France to keep hailstones small and common salt has also been suggested (Ludlam, 1958). This is in line with the thinking of Foster (1961) that if the number of nuclei for the formation of ice crystals are increased, then the number of smaller hailstones will be increased. In northern Italy, 270 rockets were fired in the hail season of 1949 and 10,000 in 1955. Various countries, including the U. S., Australia, England, Spain, and France also have tried rockets. List (1963) and Battan (1963) studied the effect of the blast wave of exploding rockets on hailstone size. Vittori (1966) and Favreau and Goyer (1967) argued that shock waves from exploding rockets would cause cavitation in hailstones and break them up. List (1963) concluded that there was no justification for combat-

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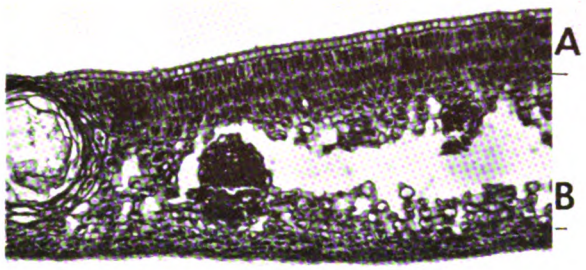

Fig. 10–47. This trans-section of a Eureka lemon leaf which has been frozen, shows water marks and splitting of the mesophyll. *A*, palisade and upper spongy mesophyll; *B*, lower spongy mesophyll.

ing hail by softening it with exploding rockets, and Dessens (1967) stated that such experiments have been inefficient. Since it is not possible to fly any except a few aircraft through hail-producing storms, progress in this field will depend on information obtained by dropsonde, a meteorological sounding device dropped from aircraft to obtain a record of conditions above, in, and below hail-producing and other very severe storms (Anonymous, 1966).

NATURE OF INJURY AND RECOVERY OF LEAVES AND FRUIT

Leaves

At night it can generally be observed with an electric torch that leaves on the skirts of trees appear water-soaked when air temperatures go below 25° F. Leaves take on a greasy appearance (Knorr, Suit, and DuCharme, 1957). After sunrise, unless water-soaked leaves are tagged, it is impossible to distinguish frozen leaves from unfrozen, since the mesophyll cells of frozen leaves reabsorb water that has filled the intercellular space during the cold hours of the night and the leaves are undamaged. If the brittle water-soaked-looking leaf is broken while still freezing and the epidermis stripped open suddenly between the fingernails of the thumb and forefinger of each hand, the frozen water, snowlike in appearance, will fly out as though under pressure. It definitely can be stated that as leaves cool water flows out of the mesophyll cells into the intercellular spaces and subsequently freezes. This is known as intercellular freezing.

Intercellular freezing is common, and frost damage usually does not occur unless the volume of ice formed in the intercellular space is greater than the volume of the space. Splitting of the leaf lamina then occurs in the watermarked leaves, as shown in figure 10–47. Then desiccation occurs and the leaf fails to recover. Young and Peynado (1967*a*) found that subsequent death of leaves having a water-soaked appearance is not of frequent occurrence (table 10–12). In intracellular freezing, however, ice crystals form inside the cell and damage the internal components of the cell, usually in a lethal fashion. It is not known how the lethal damage occurs in the cell, but a considerable body of evidence has been amassed indicating several possible ways. This will be discussed elsewhere. Whether the yellowing of citrus leaves on the south sides of trees is a result of either of these types of injury or whether this is a simple breakdown of chlorophyll at temperatures near 40° F is not known (Cooper, Rasmussen, and Waldon, 1969). However, running wind machines late in the morning i.e., one or two hours after sunrise) generally eliminates this difficulty by producing uniform temperatures in the orchard (Turrell and Austin, 1966*b*). Most tissues will undercool (super cool), and as long as freezing does not occur, no injury results. This has generally been observed in citrus tissues by the author and his coworkers and by Hawkins *et al.* (1949), in potatoes by Wright and Taylor (1921), and in apples by Diehl and Wright (1924). The severity of frost injury depends much on the de-

Table 10–12
RECOVERY OF FROZEN AND WATER-SOAKED LEAVES

Variety	Minimum Air Temperature (°F)	Frost in Tissues	Number of Water-Soaked Leaves Recovered (Per Cent)
Satsuma mandarin	23	none	100
Valencia orange	12	none	0
Redblush grapefruit	12	none	0
Redblush grapefruit	23	light	85
Valencia orange	23	light	85
Redblush grapefruit	26	heavy	90
Satsuma mandarin	28	moderate	100
Valencia orange	28	moderate	95
Mexican lime	28	moderate	5
Satsuma mandarin	29	heavy	100
Valencia orange	29	heavy	100
Kara mandarin	29	heavy	100
Nagami kumquat	29	heavy	100

Source: Young and Peynado (1967*a*).

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gree of maturity. Actively growing foliage is much more susceptible to freeze damage than nongrowing, mature tissues (Fawcett, 1936). Slight amounts of freezing turn these tissues black because of contained chlorogenic acid. Young but nongrowing leaves are more freeze resistant than older ones.

Fruit

In general, there are two kinds of frost injury that occur in fruit: peel and pulp damage. Peel damage is associated with wet nights and seems to be related to oleocellosis, in which oil is extruded to the peel surface and remains on the surface long enough to cause the death and shrinkage of cells between the oil glands. When freezing is quite severe, watery patches occur in the rind, and these are soon invaded by fungi (Fawcett, 1936). So far as is known, there is no recovery from this kind of damage.

Internal effects of freeze, such as water soaking of the membranes and the precipitation of hesperidin on the membranes of orange fruits or in the pulp of tangerine fruits (naringin in) grapefruit) are visible from five to ten days after a freeze. Juice vesicles which are frozen lose their juice, which appears to move into the peel where the water is transpired. The vesicles then collapse. Thus, the vesicle content of entire segments may be destroyed and a hollow segment remains. The Valencia orange which is not ripe during winter suffers this injury as do lemons and grapefruit because of the low soluble solid contents of their juices. Both grapefruit and lemons will recover from this kind of freeze injury in southern California, but recovery is most complete and common in Valencia oranges, probably because of the long period that the fruit remains on the tree before maturity and picking (12 to 18 months). New vesicles develop from the side and end walls of segment membranes and refill the segments. The carotenoids that disappeared reappear after about three to four months, and the former partial pale-grey, milky color also disappears. Nearly all the hesperidin crystals are reabsorbed after about three months. The wavy segment walls, water-soaked, gelatinous and thickened improve in appearance but are not restored to their prefrozen condition. Certain vesicles gelate, but after four months juice is free running in all vesicles and no correlation has been found between granulation and the severity of freeze damage. The amount of juice, the per cent of reducing and nonreducing sugars, total sugars, soluble solids, and free acids are lower in the frozen fruit than in the nonfrozen. While the steady rate of gain in percentage of constituents indicates recovery, no acceleration takes place (Bartholomew, Sinclair, Horspool, 1950).

Following the freeze of mid-November, 1958, Turrell and Austin (1960*b*) reported on the freeze recovery of fruit in a study of forty-six orchards in southern California. Recovery resulted from the melting of the ice, formed in the fruit a few hours after sunrise. The findings of their nine-month assessment are shown in table 10–13 for Washington navel oranges and in table 10–14 for Valencia oranges. The amount of immediate recovery from freezing, determined by cutting the fruit, is the difference between percentage of fruits frozen and percentage of fruits damaged. Where the orchard had sufficient water and wind-machine protection, there often was considerable recovery of frozen fruit within a few hours, even though heaters were not used. In contrast to the findings of Bartholomew *et al.* (1950), all (100 per cent) of the Valencia oranges which were cut were at least partially granulated, and considerable granulation was found in the Washington navel oranges. It is not clear why granulation sometimes occurs in Valencia orange fruit, together with refilled or freeze-recovered segments, some six to ten months after a freeze, as described by Bartholomew *et al.* (1950).

What to do with frozen fruit depends on the degree to which the fruit are damaged. A very severe cold temperature may kill all the cells in the pedicels and fruit will hang on the tree even though 95 per cent of the pulp is damaged. A less severe freeze will allow a few cells in the pedicels to survive. Ethylene and enzymes remain active, the abscission zone functions, and most of the crop may drop to the ground with less than 5 to 10 per cent of the pulp of each fruit damaged by frost. Grapefruit taste may be improved by slight freezing. The decision of when to pick frost-damaged fruit varies considerably with the nature and extent of tissue damage and subsequent weather conditions, and should be left to those with considerable experience with this problem.

TREATMENT OF FROST-DAMAGED TREES

Frost damage to foliage, fruit, and twig growth may be visible in two days to a week after the occurrence of freezing temperatures. Damage to branches and old limbs may not be evident in two or four weeks, or even several months. At the

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Table 10–13

ORCHARD MANAGEMENT AND FRUIT RECOVERY AFTER THE BLACK FROST OF THE NIGHT OF NOVEMBER 16–17, 1958 WASHINGTON NAVEL ORANGES—INTERIOR CLIMATIC DISTRICT OF CALIFORNIA*

Grove No.	Type of Wind Machines	Heaters (Per Tree)	Date of Last Irrigation	Minimum Temperature (°F)	Hours Below 32°F	Fruits Frozen (Per Cent)	Fruits Damaged (Per Cent)	Damage per Fruit (Per Cent)	Fruits Granulated (Per Cent)	Leaf Damage (Per Cent)
					Riverside					
1	None	½	Day prior	22	8	80	56	5.14	18	0
2	Large dual (V8)	†	Nov. 9	24	8	60	15	0.53	30	0
					Elsinore					
3	None	Few	Day of irrig.	22	11	100	100	43.67	....	....
4	None	....	Day prior	19	11	96	92	42.26	....	41
5	2 electric, 12½ hp	Few	Day prior	19	11	81	51	9.54	15	19
6	125 hp—V8	¼	Two days	22	9	37	30	2.99	....	....
7	Large dual	None	Day prior	19	....	94	58	21.19	18	....
8	Distant	None	Day prior	19	11	100	98	70.20	57	....
9	Near (large dual)	None	Day prior	19	11	92	42	7.68	34	....
10	None	None	Day prior	19	11	95	70	8.50	30	....
11	None	None	Day prior	19	11	100	84	35.98	8	....
12	Small electric	Few	Day prior	19	11	100	74	22.49	31	....
13	None	None	Two weeks	....	....	78	78	25.61	3	....
14	Electric, 12½ hp	⅓	One month	21	11	100	100	48.90	....	....
15	None	⅓	One month	21	11	100	100	84.40	....	....
16	None	None	One month	18	....	98	98	100.00	....	....
17	None	None	Ten days	18	....	100	100	100.00	....	90–100
					Hemet					
18	Dual of single (V8)	½	Day prior	24	10	53	5	1.18	37	....
19	Three duals (V8)	½	Day prior	24	10	47	3	0.06	18	....
					Escondido					
20	None	¼	Day prior	26	....	....	34	3.00	....	....
					Sunnymead					
21	Electric, 35 hp	¼	Nov. 3	24	8	91	0	0	40	....

* Only one serious frost occurred during the 1958–59 winter. Light rains of not more than 1/10 inch were all that fell on any one day until February 8 or 11. Rare ideal weather conditions existed for assessing (cutting fruit) and photographing leaf frost damage for three months. All leaf damage was recorded before January 1, 1959; fruit damage, December, 1958 through February, 1959 (Turrell and Austin, 1960*b*).

† Around edges of orchard only.

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Table 10–14

ORCHARD MANAGEMENT AND FRUIT RECOVERY AFTER THE BLACK FROST OF THE NIGHT OF NOVEMBER 16–17, 1958
VALENCIA ORANGES—INTERIOR CLIMATIC DISTRICT OF CALIFORNIA*

Grove No.	Type of Wind Machines	Heaters (Per Tree)	Date of Last Irrigation	Minimum Temperature (°F)	Hours Below 32°F	Fruits Frozen (Per Cent)	Fruits Damaged (Per Cent)	Damage Per Fruit (Per Cent)	Fruits Granulated (Per Cent)	Leaf Damage (Per Cent)
					Corona					
22	Electric, 75 hp	None	Day prior	23	9	88	84	14.98	100	14
23	Electric, 75 hp	None	Day prior	23	9	66	56	4.64	100	14
24	None	None	Day prior	23	9	84	72	11.50	100	6
25	Gas (not oper.)	None	Day prior	23	9	96	96	18.76	100	9
26	Gas (not oper.)	None	Day prior	23	9	100	98	25.14	100	32
27	Diesel	None	Grove dry	23	9	86	84	11.28	100	14
28	Diesel—until 4:45 A.M.	None	Grove dry	23	9	98	98	34.10	100	57
29	None	None	Grove dry	23	9	98	84	14.94	100	7
30	Not oper.	None	Oct. 22	20	9	94	88	22.60	100	13
31	Not oper.	None	Oct. 22	20	9	100	98	45.30	100	66
					Anaheim					
32	Gas—dual (V8)	None	10 days	24	10	4	2	0.10	100	....
33	None	None	10 days	24	10	2	2	0.04	100	....
34	None	None	10 days	24	10	0	0	0.00	100	....
					Elsinore					
35	None	Few	Day prior	19	11	98	95	39.65	100	42
36	Small elec.	Few	Day prior	19	11	70	64	8.36	100	10
37	None	Few	Day prior	19	11	64	58	6.18	100	6
38	None	None	2 weeks	....	....	96	84	15.18	100	29
39	Small elec.	None	Day of irrig.	19	11	92	64	8.14	100	13
40	None	None	Day of irrig.	19	11	100	98	37.88	100	43
					Hemet					
41	None	½	Day prior	24	10	0	0	0	100	0
42	Gas—single	½	Day prior	24	10	0	0	0	100	0
43	Gas—dual	½	Day prior	24	10	0	0	0	100	0
44	None	½	Day prior	24	10	0	0	0	100	0
45	None	½	Day prior	24	10	0	0	0	100	0
					Escondido					
46	None	¼	Day prior	26	....	....	9	0.39	100	....
					Coastal Climatic District (San Juan Capistrano)					
47	2 electric, 25 hp	½	Two weeks	32	10	0	0	0	100	....
	1 electric, 15 hp	½	Two weeks	32	10	0	0	0	100	....
48	2 electric, 40 and 50 hp	½	Oct. 26	25	10	10	9	0.33	100	....

* Weather conditions were as described for the winter of 1958–59 in table 10–13. The spring and summer of 1959 were dry and hot for additional growth and maturation of Valencia oranges (table 10–14). All orchard thermometers, weather data, orchard characteristics, and operations during the frost were checked between March and June. Leaf damage was photographed during the same period as for Washington navel oranges. Freeze damage assessment of fruit which had affected pulp but not peel was determined by complete cutting of fruit in July, August, and September when Valencia oranges were ripe.

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end of the summer following the 1962 Florida freeze, cankers (a result of the freeze) appeared which had not been visible on old limbs earlier. Thus prompt pruning, which seems so desirable from the appearance standpoint, should rather be guided by the degree of freeze damage. For light damage, the time interval is not critical, but following heavy freezes, if the decision has been made to keep the trees, pruning should be deferred for six to twelve months or longer after the freeze, until the time when the extent of the damage can be determined with certainty and the tree is out of danger of a second freeze. However, late pruning will result in more interference from new growth. Early pruning generally results in removal of some limbs that will recover, and leaving some that will die back.

The rehabilitation program for the woody frames of frozen trees will depend on a number of factors: the age of the trees, the degree of injury, the availability of new trees and their cost, the availability of labor, the part of the country, kind of soil, the value of the land, the costs of grove maintenance, and the chances for a succeeding freeze in the present season and the following year. When it is possible to make some kind of estimate of freeze damage (in part, this may be surmised from the minimum temperatures and their durations in the orchard), it is well to consider that slight damage may be concurrent with stimulation of feeder-root growth, but that somewhere in between, mild retardation of root growth is associated with defoliation, and 97 per cent loss of feeder roots is associated with severe wood damage (Ford, 1963). There must, therefore, be a graduated scale of feeder root damage between these points. Good recovery is also dependent upon mild weather, perhaps cloudy to rainy weather at the outset, without dry north winds or bright sunshine to inhibit good root growth. With so many variables, considerable care and good judgment are needed in selecting the rehabilitation program. Perhaps the best aid to judgment is making acquaintance with what has been said on the subject in a general way by Blanchard (1937), Cooper (1963*b*), Cooper, Rasmussen, Peynado *et al.* (1963), Ford (1963), Jackson (1963a, 1963*b*), Johnston (1963), Knorr *et al.* (1957), Lawrence (1963*a*, 1963*b*), Parker (1964), Reitz (1963*a*, 1963*b*), Shamel (1937), Sharp (1937), Wight (1939), Yelenosky, Register and Hearn (1965), and Young (1963*d*).

Light Damage Early in Season

When only foliage leaves and small twigs or new growth are damaged *no pruning* should be done. Pruning invigorates freeze-damaged trees (Kretchman and Jutras, 1964). All grove practice should be such as to keep the orchard dormant. Dormancy is recovered by about seven to ten days of warm temperatures from 65° F to 75° F (Young and Peynado, 1961, 1965) and the grower cannot control this. Dormancy is also influenced by moisture.

In California, it is recommended that groves be kept on their regular irrigation schedule, because the normal cool nights keep the trees fairly dormant. In Texas and Florida, nights are generally warmer so that trees are on the verge of a flush of growth almost any time during the winter season. Lack of moisture keeps them dormant and irrigation is not recommended for Florida or Texas. If the trees flush new growth, a second freeze is most harmful to such susceptible extension. Tree banks in Texas and Florida should be kept in place up to February 15. Chlorodane is helpful in tree banks in Florida. Fertilizers are also withheld, as are insecticidal and fungicidal sprays with added minor elements, providing the pest population growth is not too rapid. Under no circumstances should oil sprays be used; they make the tree very susceptible. Maleic hydrazide spray (MH-30) offers small promise for maintaining dormancy of damaged trees. Reitz (1963*a*) suggested applying MH-30 at the rate of one quart per hundred gallons of water (1,000 ppm) to trees when leaves have dropped and buds begun to swell. This should be applied to wood when necessary to retard growth until mid-February. The U. S. Food and Drug Administration has not approved MH-30 for use when trees carry marketable fruit. Clean cultivation should be practiced and the cover crop should be cut down. Herbicides should not be used near frost-damaged trees.

Light Damage After Frost Season

Lightly damaged trees offer considerable promise for a new crop. After the middle of February and by the middle of March lightly injured trees should be brought into normal grove maintenance. Irrigation should be carried out if it is needed (new growth should not be allowed to wilt). The ground should be reasonably moist as indicated by tensiometers (see chap. 8, p. 232). The trees should be fertilized. Nutritional leaf

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sprays (nitrogen and minor elements) may be applied if needed. Pruning may be done after one flush is matured and hardened (May or June). Any wood cut over one-half inch in diameter should be painted with a water-repellent tree paint. The insect and fungus population should be carefully watched and the proper sprays applied (Lawrence, 1963*b*).

Parathion or copper sprays (post-bloom sprays) may be applied one to three weeks after petal fall. A spray program should be developed for the particular area in consultation with the farm advisor. Limbs one inch in diameter and larger when removed should be cut flush with the parent branch. Short stubs seldom heal over (Young, 1963*d*). Where bark has split on the trunk of young trees, this may be satisfactorily repaired by binding it with plastic tape, masking tape, or cotton cord (Miller, 1968). Satisfactory repair of split bark in Texas was obtained after the 1962 freeze by Shull (1968) by simply nailing the curling bark to the wood. But after the 1951 freeze in Texas split bark was not successfully wrapped to the wood of the trunk. Fungus infection was largely responsible for the failure (Cooper, 1968). Another method has been to cut out the dead areas of the bark smoothly and disinfect and paint the exposed wood. Use of wax and sealing paints or budding cloth favor the development of gummosis, and should be avoided.

Moderate to Heavy Damage, Early in Season

With small or young trees with damaged trunks and split bark, one should withhold any but moderate applications of water, withhold all fertilizer, and not prune. It may be to the advantage of the grower to pull the trees and replant. With larger trees, even with crowns badly damaged, if trunks are in good condition, it may be to the grower's advantage to rebud these trees later (Blanchard, 1937). One should consider intersetting when danger of cold is past (Savage, 1963), since it may offer a distinct economic advantage.

Moderate to Heavy Damage Late in Season

When almost all danger of frost is past, usually after the middle of February, obviously dead wood should be pruned. (Not all danger is past in February, however, since there have been frosts after this month both in Florida, two of them in the middle of March, 1958, and in California in April, 1968, although they are extremely rare.) Dead wood weakens the tree (Young, 1963*d*). Further pruning can be done in the fall. Fertilizers also may be applied. It must be realized that about 70 per cent of the nitrogen in the tree is in the leaves, and this will need replacement since they have fallen. Irrigations should be on schedule, and pest control sprays may be needed. These may be combined with minor element sprays containing zinc, copper, and manganese. Exposed trunks and large, nearly bare limbs on defoliated trees should not be sprayed with whitewash to prevent sunburn as this retards the growth and recovery of the tree (Webber, 1937*b*). Water-base paints recently have been found to give good sunburn protection (Micke, Beutel, and Yeager, 1966). With lemons, protection is sometimes needed after defoliation, especially on light, bare, reflective soils. Upper surfaces of horizontal limbs and south sides of exposed trunks should be sprayed. Pressures below 300 psi and use of a Number 9 disc ($\frac{9}{64}$-inch) for spraying are recommended. Zinc should be in the first sprays applied. Large defoliated Valencia orange trees and groves that normally would have to be hedged can be advantageously hedged now, especially if the fruit has been picked as in Florida or dropped and the outlook is not too promising for the next season (Lawrence, 1963*b*). In Florida and Texas, trees that have been banked should be unbanked.

Severe Damage Late in Season

When injury extends down the trunk, killing all scion wood, sprouts can be forced and the tree rebudded. The dead stump is cut away as much as possible. Cuts are treated with Avenarius Carbolineum and then coated with heavy pruning paint (Parker, 1964). Where a large root system is still intact, although there may be a few defects in the wood frame, it is often advantageous for a grower in Florida or Texas to rebuild the tree (Young, 1963*b*). Because of high labor costs and other economic considerations, it is often advantageous in California to pull out the severely damaged trees and replant or interplant (Johnston, 1963).

Fall Management of Freeze-Damaged Orchards

The trees should go into the winter period with as little new vegetative growth as possible and become dormant. The pests should have been controlled, but no oil spray should be used. Cover crop and weeds should have been replaced by clean cultivation (Anonymous, 1963*a*). The trees

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that are damaged are sensitive to herbicides, however, and a light top cultivation may be preferable. In Florida and Texas, dormancy can be induced to a degree by withholding irrigation. In California and Arizona, trees should be kept on their regular irrigation schedule. Dry trees in the latter states will suffer severely if a second cold winter develops, and usually cold winters come in pairs. No pruning should be done as this will stimulate vegetative growth of trees. Also, pruning opens the canopy so that radiant and convective heat are lost. Cooper and Hendershott (Norris, 1963) showed that temperatures of 25° F are disastrous to heavily pruned trees. All trees should be banked in Texas, and many would be greatly helped by banking in Florida (Norris, 1963). Every effort should be made to supply the needed cold protection for the second winter. Trees are now much more vulnerable to cold damage, and protection from heaters, wind machines, water, solid fuels, and by other means will pay off handsomely (Jackson, 1963*a*, 1963*b*).

Treatment of Wounds

All large pruning cuts should be immediately disinfected. Frost wounds may be disinfected at convenience, but both types of wounds should be disinfected in the fall before the rainy season. Disinfectants are most effective in coastal climates where humidity is high. Commercial formulations of Bordeaux spray may be used as disinfectants or one teaspoon of potassium permanganate per pint of water. Commercial formulations of water-emulsified asphalt may also be used as a wound paint.

COLD HARDINESS OF SCIONS AND ROOTSTOCKS

The citrus-growing areas of the United States are subject to freezing weather sufficiently cold to cause severe damage and loss of citrus orchards about once in ten years on the average. However, each area also is subject to radiation frosts of some severity. Varieties and strains of citrus which are completely or partially cold hardy are most desirable. A breeding program to obtain frost-hardy varieties has been led by W. C. Cooper (Cooper, Reece, and Furr, 1962), in the U. S. Department of Agriculture for several years.

Cooperative studies by state experiment stations show that while cold hardiness is genetically controlled it is greatly enhanced by a few days of low air temperature (60° F day, 40° F night), and the induced hardiness may be removed by a few days of warm air. Thus, whatever the inherited cold hardiness trait might be, the degree to which it appears to react in the environmental frost depends upon its immediate past temperature history, including both above ground and soil temperatures. For instance, in California the ambient air temperature usually falls in winter below 40° F at night, and the soil temperature at the one foot depth often falls to 50° F or below (see chap. 9). The minimum temperature for growth is about 50° F. In Florida and Texas, on the other hand, nocturnal ambient air temperature normally falls below 50° F only about a dozen times during the winter. Large plant parts such as trunks and limbs of trees may average above 60° F (Cooper, Young, and Turrell, 1964), and soil temperatures mostly remain above 60°F (see chap. 9).

Cold hardiness of leaves of different ages vary. Young citrus leaves are most susceptible from time of emergence until fully expanded. After reaching full size, they are most resistant. Then they become progessively more susceptible with increasing age, according to studies made with detached leaves (Cooper, 1965).

Cold hardiness of stems is dependent on the dormancy of the cambium. The leaves may be cold hardy, but the trunk, branches, and twigs may grow rapidly if there is soil moisture. The cambium is thus active, and these tissues are susceptible to cold injury.

Little information is available about the plant characteristics or cell characteristics which promote frost hardiness. However, Kuiper (1969), working in the author's laboratory, developed some interesting leads which may be helpful. The previous work of Lyons, Wheaton, and Pratt (1964) showed that the mitochondria from chilling-resistant plants contained a larger amount of polyunsaturated fatty acids than mitochondria from chilling-sensitive plants. Also, the studies of Gerloff, Richardson, and Stahmann (1966) showed that the hardening process changed the fatty metabolism of alfalfa roots so that the fatty acid composition of the roots changed with the result that polyunsaturated fatty acids such as linoleic and linolenic acids accumulated. With these findings in mind, Kuiper (1969) investigated the lipid composition of leaves of citrus plants that had undergone the December, 1967, freeze in Hemet, California. Marsh grapefruit and Eureka lemon are relatively frost susceptible, while Dancy tangerine and satsuma are relatively frost-resistant

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Table 10–15
LIPID COMPOSITION OF CITRUS LEAVES OF TWO FROST-SUSCEPTIBLE VARIETIES AND TWO FROST-RESISTANT VARIETIES EXPRESSED AS PERCENTAGE OF TOTAL LIPID

Varieties	Neutral Lipids (Per Cent)	Glycolipids (Per Cent)	Phospholipids (Per Cent)
Susceptible			
Marsh grapefruit	59	30	11
Eureka lemon	60	29	11
Resistant			
Dancy tangerine	56	25	19
Satsuma tangerine	52	33	15

Source: After Kuiper (1969).

varieties. No lemon trees survived the freeze in Hemet, and therefore leaf material was obtained in nearby Riverside. It can be seen in table 10–15 that the frost-resistant Dancy tangerines were low in neutral lipids and in glycolipids, but that they were high in phospholipids as compared with the leaves of frost-susceptible grapefruit and lemon trees.

Citrus trees such as citrons, lime, and lemon, which tend to grow continuously and to fruit and flower in cool weather, are the most susceptible to frost. It has been assumed that this is because they are always in an active stage of growth. Trees such as grapefruit and sweet orange (round oranges) are moderately susceptible. These stop growth in cold weather as do sour oranges, mandarins, and Meyer lemon, which are frost hardy, and kumquat and trifoliate orange, which are very hardy.

Young (1963*a*) studied the relation of cold hardiness to climate. Cold hardiness of citrus trees in mid-winter is usually greater than in fall or spring, and actively growing trees are less cold hardy than dormant nongrowing ones. Williams (1911) early observed that trifoliate orange rootstock produced hardiness in the scions. He attributed this to the production of dormancy in the top, and the maintenance of this despite warm spells in January and February. Milliken, Tylor, Bonns *et al.* (1919) also observed the tendency of trifoliate orange rootstock to produce frost hardiness in lemon trees. Also, navel oranges on trifoliate rootstock are more frost hardy than navel oranges on sweet orange rootstock. Rough lemon seems to be among the most tender rootstocks, sweet orange is next in degree of tenderness, sour orange is fairly hardy, and trifoliate orange very frost resistant. Uphof (1938) found in Florida that Parson Brown, Hamlin, Pineapple, and Valencia oranges and Duncan, Hall, Walters, and McCarty grapefruit are relatively frost hardy on sour orange rootstock and very frost hardy on Cleopatra mandarin and trifoliate orange. All are tender on rough lemon rootstock.

Olson and Maxwell (1964) observed the cold hardiness of tangerine-hybrid varieties in the Texas freezes of 1949, 1951, and 1962. The Clementine variety of mandarin was the most cold hardy of any of the varieties, while the Owari satsuma, also of the mandarin type, was next. The Dancy in the group was not very cold hardy. The Wilking and Kara varieties are hybrids with many excellent characteristics, including cold hardiness of the trees. All of the trees of the tangelo group are cold hardy, but various shortcomings limit the commercial usage of some.

Furr, Brown, and Olson (1966) found Clementine seedlings by Tankan were the most cold tolerant of the crosses made at Indio, California, based on leaf damage in a natural freeze. At Port Sulphur, Louisiana, the crosses were scored on the basis of both leaf and stem damage in a natural freeze. In the latter, all progeny of Changsha mandarin were highly cold tolerant.

Young and Peynado (1967*b*) artificially froze 69 three-year-old citrus hybrids and varieties in a forced-draft portable tree freezer. There were fourteen types budded on sour orange rootstock, fourteen on Carrizo, and fourteen on citrange. The Orlando (Duncan × Dancy, parents) and Lee (Clementine × Mott) on sour orange rootstock were the hardiest, judging by defoliation and wood injury. Citrange rootstock did not induce as great cold hardiness as sour orange. Maxwell (1967) tested five varieties and strains of nine-month-old trees of mandarins and one early orange variety on sour orange rootstock at Winter Park, Texas. The satsuma mandarin showed the least defoliation and wood damage and was the most cold hardy. Maxwell and Wutscher (1968) tested two clones of tangerines, namely Fairchild and Bower, in two rootstock tests of ten single-tree replications with six different rootstocks. The Fairchild tangerine scion on Morton Citrange and Changsha mandarin rootstocks were fairly cold hardy. The Bower scions as usual were less cold hardy than the Fairchild scions, regardless of the rootstock used.

Hearn, Cooper, and Register (1963), Hearn, Cooper, Register *et al.* (1963) and Young (1963*b*, 1963*c*) observed the injury and recovery of various

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scions on various rootstocks for leaf and wood response. In Florida, Orlando tangelo and Hamlin orange were found to be the most cold-resistant varieties. In descending order of cold resistance, these are followed by Valencia orange and grapefruit. The rootstocks had a striking effect on cold resistance. Cleopatra mandarin and sour orange rootstocks were more resistant than most varieties including rough lemon. In Texas, Frost navel oranges and hybrid scion 6–5–15 were least injured, while Cleopatra mandarin was consistently better than sour orange as a rootstock. Dancy tangerine, which is hardy in Florida and California, was not cold hardy. Young (1963*b*, 1963*c*) in Texas also found that nine- to thirty-six-month-old seedlings and four- to nine-year-old cultivars of *Poncirus trifoliata* and its hybrids were least injured in the 1962 freeze. Frost injury occurred in increasing amounts to oranges, tangelos, grapefruit, limes, and lemons. Mandarins showed variable degrees of injury. Cultivars with the most frost damage showed the poorest recovery. These observations confirm the results of Hodgson (1933), Webber (1948), and Young and Olson (1963). For the colder northern area of Texas (Winter Garden), Creel and Olson (1963) also found that Washington navel orange trees on Cleopatra mandarin rootstock were outstanding in their cold resistance.

The early studies of Lawless and Camp (1940) and Lawless (1941) indicated that deficiencies in minor elements and in nitrogen, phosphorus, or potassium made various varieties more susceptible to frost damage, probably because of the associated sparse foliage. Later studies by Reuther and Smith (1954) and Maxwell and Shull (1963) showed that unless there were minor element deficiencies, treatment with minor elements did not increase the cold hardiness of citrus varieties, and that the amount and timing of nitrogen above deficiency did not increase their vigor or cold hardiness. Peynado and Young (1963*a*) found that high salt concentrations in the soil decreased the cold tolerance of grapefruit trees in the order $CaCl_2 > NaCl > Na_2SO_4 >$ control. These observations lend support to the view that cold hardiness is a genetic character modifiable by environment.

PART II. PHYSICS AND PHYSIOLOGY OF FROST PROTECTION

The data, information, and discussions presented in this section are addressed primarily to advanced students and those concerned with research and development in the field of frost protection. The last few decades have seen important progress in our understanding of weather phenomena of all kinds and their physical bases. In addition, there have been significant advances in our insights into course, nature, and mechanism of freezing injury in plant cells. This second part of the chapter attempts to summarize knowledge in these areas which has a bearing on frost protection.

HEAT TRANSFER

Heat transfer is the basic physical process involved in frosts and freezes. Both frosts and freezes are the result of the transfer of terrestrial heat from the ground, plants, and atmosphere near the ground to the atmosphere farther out in space. Heat is always transferred from the body or gas of the higher temperature to that of the lower temperature. The four methods by which heat is transferred are radiation, convection, change-of-state processes involving latent heat, and conduction. Solids, liquids, and gases also store heat to varying degrees. This stored heat is referred to as enthalpy. Each of the methods of storing and transferring heat by terrestrial bodies may combine with those of the atmosphere and are referred to by more specific terms.

Radiation

The transfer of heat from one body to others without apparent dependence on a medium is referred to as radiation. Light and heat pass through the volume of the ordinary Mazda lamp, sun light through interstellar space, and heat from a radiant heater between the molecules constituting dry air. Heat travels in straight lines, and, since no medium of transfer is involved, it can't be diverted by wind, but is reflected by mirrors and refracted by lenses and prisms. As with radio, heat travels in waves (at the speed of light) which are characterized by wavelength, the distance between two adjacent wave crests. Very hot bodies radiate energy of short wavelengths (0.3 to 0.7 μ) that are detectable by the eye and referred to as visible light. Bodies which are warm to the touch radiate in the long infrared range a peak percentage of energy ranging from 8.9 μ to 10.4 μ principally. Infrared film will detect wavelengths of

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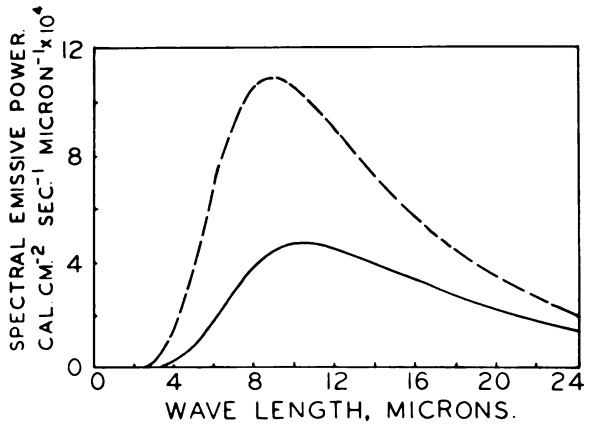

Fig. 10–48. Energy distribution for black body radiation at two temperatures. Peak radiation energies correspond to terrestrial temperatures on a cold night (0° C, maximum percentage equal to 10.6 μ, lower curve) and for a body in sunshine on a hot day (50° C, maximum percentage equal to 9.0 μ, upper curve, for ϵ = 1.0). Leaves, fruit, and stems are grey bodies (ϵ = 0.87 to 0.95), and thus absorb less radiation and radiate less energy for corresponding temperatures than black bodies. (Adapted from Beese, 1942, and Canada, 1948. Courtesy of R. L. Perry.)

0.7 μ to 1.6 μ. Infrared spectrometers and radiometers are used to detect and measure longer wavelengths. An infrared photograph of warm and cold grapefruit, in total darkness, taken with an infrared camera by the heat radiated from the fruits themselves, is shown in figure 10–48. Such a radiator gives a spectrum of all wavelengths, but the highest percentage of any wavelength depends so definitely on the temperature of the body that the temperature can be used to characterize the wavelength of radiation (see fig. 10–48).

Where λ_m is the wavelength of maximum emission, e_m is the maximum amount of radiation (monochromatic) at temperature T in degrees Kelvin, and α is a constant ($\alpha = 0.2885$ cm degrees), this relationship is expressed by the equation

$$\lambda_m = \frac{\alpha}{T} \qquad (1)$$

The relationship is important because if the temperature of a citrus leaf is known, the principal wavelength of radiation from the leaf may be calculated and the percentage of radiation absorbed by water vapor in the air may be estimated.

If infrared radiation, I, impinges on the surface of a citrus leaf, the major part will be absorbed at the surface (the rougher the surface, the greater the absorption). This percentage may be designated as α, and the percentage reflected may be designated R. The relationship is expressed as

$$I = \alpha + R \qquad (2)$$

The amount of visible or infrared energy absorbed by the leaf, etc. may be reradiated at longer wavelengths in the infrared. The rate at which the leaf, fruit, or wood ("grey bodies") reradiate at a given temperature in comparison to a black body at the same temperature is the emissivity, ϵ, and $\epsilon = \alpha$. It is therefore possible by measuring infrared reflectance to calculate emissivity, which is an important factor in the equation of heat transfer by radiation.

The rate of heat transferred in cal/cm^2 sec °C or BTU/ft^2 hr °F is termed conductance, h. Radiation conductance = h_r, and may be calculated from the following equation when ϵ has been determined:

$$h_r = \frac{\epsilon\sigma(T_l^4 - T_s^4)}{(T_l - T_s)} \qquad (3)$$

and the Stefan-Boltzman constant, $\sigma = 1.37 \times 10^{-12}$ cal/cm^2 sec °K^4, the subscripts l and s indicating leaf blade and sky respectively.

Convection

Convection is the transfer of heat by moving matter. It results in the upward burning of a candle flame. In a glass coffee pot filled with water, heat is transferred from the fire through the bottom of the pot to the liquid and through the liquid at first by conduction. When bubbles form which stir the liquid, heat transfer is then by convection. Actually, before boiling is reached, heat is transferred through the water by convection, as can be seen by clear streaming lines within the liquid. Similar streaming lines may be seen in air if a candle flame is interposed between a bright light and a screen. It is also a common experience on a hot summer day to see "heat waves" rising from a sunlit pavement. These thermally induced movements (in the first case, liquid, and in the second, air) result from warmer, lighter, less dense matter moving upward through cooler, heavier, more dense matter, and the cooler more dense matter above moving by gravity downward to replace the warm matter (i.e., liquid or gas). Natural or free convection then is the heat exchange between a solid and a fluid when fluid motion is induced by temperature differences of a solid surface and a fluid in contact with it. If the surface is warmer than the fluid, convection will be upward, but if it is colder convection will be downward. Upward convection from a horizontal irradiated leaf photographed through a Schlieren lens is shown in the upper leaf (fig.

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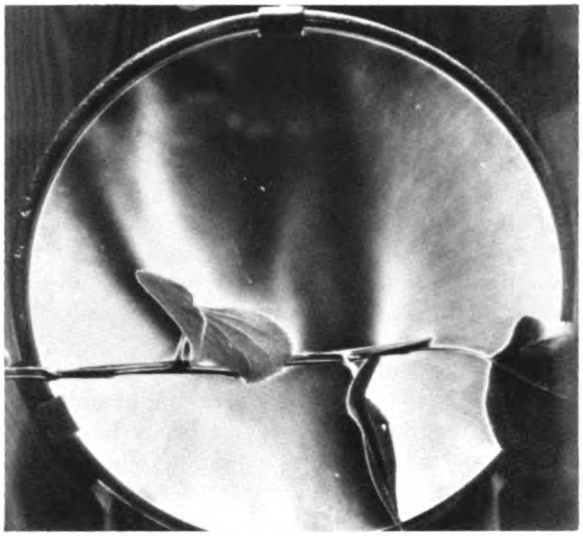

Fig. 10–49. Schlieren photograph of poplar leaves irradiated with a 3,000 foot-candle light source in still air. Heated horizontal leaf near center sends warm air current (plume) upward as depicted by light and dark streaks which indicate air of low density. Here heat is transferred by free convection. (From Gates and Benedict, 1963.)

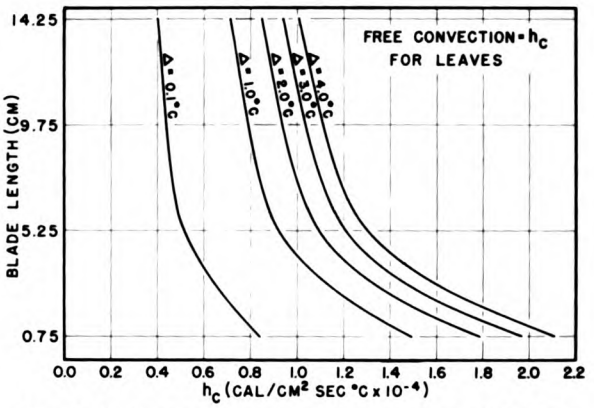

Fig. 10–50. Free convection-conductance curves for leaves of different sizes and different temperature differences between leaf and air.

10–49), as well as a slightly downward convection from the tilted lower leaf.

Air at a solid surface forms a surface boundary layer which is resistant to the transfer of heat. This is because air is a poor conductor of heat. However, heat transfer through this layer may be largely by conduction in still air. By this we mean nearly still, since air is never still and we have laminar air flow of 10 cm to 30 cm/sec even in a quiet laboratory room (Raschke, 1960). In the case of leaves, the thickness of the surface boundary layer in still air ranges from a fraction of a millimeter in small leaves to 2 cm or more in very large leaves. The driving force in free convection here is the difference in the temperature of the leaf (t_l) and the air (t_a). When the leaf loses heat by radiation to a cold nocturnal sky, the leaf will be colder than the air, and the heat gained will be transferred by free convection. The conductance by convection (h_c) can be expressed as

$$h_c = \beta \left(\frac{t_a - t_l}{D} \right)^{0.25} \qquad (4)$$

where β is a proportionality constant, which has been determined for citrus leaves to be 1.39×10^{-4} cal/cm² sec °C (Turrell, Austin, and Perry, 1962), and D = leaf width. Free convection in small leaves is considerably higher for the same Δt than in large leaves as shown in figure 10–50. Free convection plays a very important role on frosty nights when the leaf "sees" cold sky, cold ground, and cold leaves and, being therefore colder than the air, obtains heat from the air in contact with it to radiate to the cold surroundings. Because the air around citrus trees may thus become very cold as indicated by thermometers, while radiation is usually not measured, there has arisen an expression that on a frost night, citrus trees literally "freeze themselves to death." For small to medium-sized trees this is close to the truth, but not for extremely large trees, because other factors come in play, especially during single night frosts preceded and succeeded by warm sunshiny days.

Forced convection occurs when natural winds move with greatly varying velocities of above 2.5 mph, or when a wind is produced with an electric fan, wind machine, or blower. Both natural and artificially produced winds may develop turbulence in contrast to laminar flow across surfaces of leaves, fruit, and branches. Plant parts are extremely sensitive to air movement, the heat transfer in citrus increasing nearly linearly with the air velocity over a limited range. Figure 10–51 shows that forced convection conductance h_f is different for cold and moderately warm air temperatures. An equation (after Raschke, 1960) shows the heat transfer relationships for thin leaves (not applicable to thick citrus leaves) by forced convection:

$$h_f = k(\Lambda)^{-0.3}(v)^{0.5} \qquad (5)$$

where **k** = forced convection coefficient, Λ = leaf blade width, and v = wind velocity. In thick citrus leaves the relationship tends to be more nearly linear for warm air:

$$h_f = 1.97 + 0.047\, v \qquad (6)$$

At velocities below 10 cm/sec, free convection is

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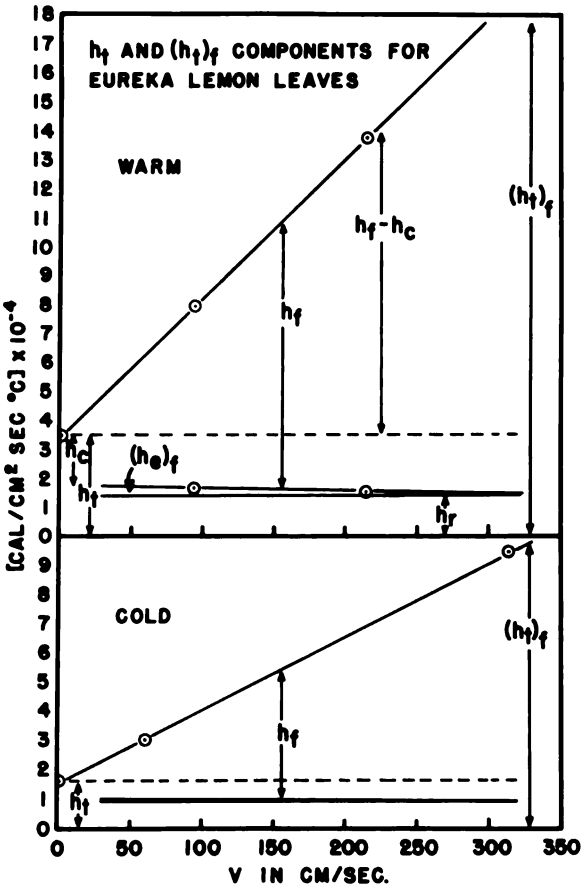

Fig. 10–51. Relative conductances of total heat transfer (h_t) for Eureka lemon leaves by radiation (h_r), free convection (h_c), transpiration (h_e) in still warm and cold air; in moving warm and cold air, forced convection (h_f), *transpiration* $(h_e)_f$ and total heat transfer $(h_t)_f$. (From Turrell, Austin, and Perry, 1962.)

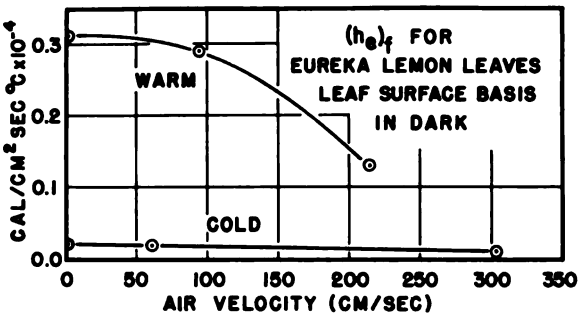

Fig. 10–52. Relative heat losses by nocturnal transpiration of Eureka lemon leaves (leaf surface basis) in still (0 cm/sec) and moving air, at cold (lower curve) and warm temperatures (upper curve). (From Turrell, Austin, and Perry, 1962.)

the predominant heat transfer mechanism, while at velocities above 200 cm/sec, forced convection is predominant, and Raschke's equation is applicable. The simplest approximation of the transition region free to forced convection is a linear tangent from the free convection conductance to the curve given by Raschke's equation. Thus in figure 10–51 the convective conductance in the transition region where a combination of both free and forced convection occurs is given by equation (6) above for warm air and equation (7) below for cold air:

$$h_f = 0.62 + 0.026\,v. \qquad (7)$$

It can be seen that if the air is warmer than the leaf, the greater the wind velocity, the greater the absorption of heat by the leaf up to the temperature when leaf and air temperature come into equilibrium. If the air is colder than the leaf (this is seldom if ever true of surface leaves exposed to the nocturnal sky during a frost or freeze), heat will be extracted at increasing rates with increasing air velocities until the leaf again reaches a steady state at a low temperature. Tree parts, such as fruit, limbs, and inside leaves, which are not exposed to the sky will be rapidly cooled, while the surface leaves may be relatively warmer than they would have been without wind. A regression equation can be used to estimate the heat transfer under forced convection where the conductance is h_f as shown in equation (7) above. The heat loss from transpiration is insignificant in figure 10–52 under near freezing temperatures, and is generally true providing dew points are not extraordinarily low. Thus we need only consider that

$$(h_t)_f = h_r + h_f. \qquad (8)$$

This situation is reflected in the regression equation for warm air (Turrell, Austin, and Perry, 1962):

$$(h_t)_f = 3.660 + 0.0467\,v. \qquad (9)$$

The regression equation for cold air is as follows:

$$(h_t)_f = 1.531 + 0.0259\,v. \qquad (10)$$

Free convection conductance and radiation conductance are nearly constant for lemon leaves as shown in figure 10–51, while the forced convection conductance increases rapidly with air velocity. All of the conductances were smaller in cold air than in warm.

Transpiration

The water loss from plants in the vapor phase is termed transpiration. Stems, flowers, fruit, and leaves all transpire. But leaves under usual conditions are the principal organs involved

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because of their large surface-volume ratios. If A = surface area, V = volume; for width, $\phi = 5$ cm and length, $l = 10.5$ cm; then, A/V for leaves = 40; for branches, 0.80; for oblate fruit, 0.81. These relations are greatly in favor of leaves because of the fact that the surface of the leaf interior tissues ("internal-surface") ranges from 10 to 30 times the "internal-surface" area (Turrell, 1936, 1964). For branches and fruit the internal exposed surface is probably much less than 10 times the internal surface. The internal surfaces of leaves are in direct connection with the atmosphere through open stomata during daylight. At night stomata are mostly closed (Ehrler, 1971), so that only small transpiration losses from leaves occur and these are through the upper and lower epidermal and outer cuticular layers. Stomata are present in other plant organs such as in young twigs (Schneider, 1955), but they are not present in old ones, which rely on lenticels for internal aeration. Fruit have stomata, but they are partially closed with loosely fitting wax plugs (Turrell and Klotz, 1940). The transpiration losses of fruits and twigs normally are much lower than those of leaves during the day, but usually are nearly the same at night. However, on nights of very low dew points transpiration losses from fruit and twigs may be much larger relative to leaves because there is no control in fruit and twigs, since the internal tissues remain open to the atmosphere.

Heat is absorbed in the evaporation of water. The rate of heat dissipation per unit leaf surface, per unit time, per degree of temperature may be expressed in BTU/ft² hr °F or cal/cm² sec °C. The amount of heat (v) required to vaporize 1 gram of water is 595.4 calories at 0° C and about 602 at –10° C. If L is the transpiration rate in gm/cm² (leaf area) per second then the total amount of heat utilized in transpiration in this case per unit leaf surface for intense daylight is

$$\frac{Lv}{2(t_l - t_a)} \qquad (11)$$

where t_l is the temperature of the leaf and t_a is the air temperature beyond the boundary layer (Turrell, Austin, and Perry, 1962; Eckert and Drake, 1959). When the leaf is being irradiated by sunlight the transpiration rate will be more intense than indicated by the temperature of the air. This can be seen from equation (1) when the driving force which is the leaf temperature in the citrus leaf is 2° C to 8° C above air temperature (Turrell and Boyce, 1953). When the leaf is exposed to a cold sky the leaf temperature may be 2° C or more below air temperature and transpiration will be less than indicated by air temperature. The greatly reduced effect of forced convection of cold air as compared with warm air on heat transfer by transpiration is shown in figure 10–53. The same equation applies for citrus fruit and limbs.

The transpiration rate (L) or the "transfer of mass" as water vapor indicated in equation (11), as has long been known, is governed by a complex of atmospheric factors which function in evaporation. In 1788, Dalton defined the laws governing evaporation in an equation which may be modified to give an approximate estimation of transpiration rate:

$$\frac{m}{\theta A} = D\frac{(p_l - p_a)}{b} \cdot 760 \qquad (12)$$

where m = mass of water evaporated, θ = time, A (area of internal leaf surface = external surface × $\frac{\text{internal surface}}{\text{external surface}}$, D = transpiration rate constant for laminar flow, p_l = water vapor pressure at the evaporating leaf surface at leaf temperature, p_a = partial pressure of water vapor in air outside the boundary layer, and b = barometric pressure (Turrell, 1964). As can be seen from equation (12) the low temperature of leaves, fruit, or branches during frosts or freezes would reduce the partial pressures of water vapor at p_l and p_a so that the mass of water transpired per unit time would be lowered and thus also the heat transfer rate. It is also apparent that although p_l may be fairly large, if the partial pressure (p_a) of water vapor in the air is very small as in the 1963 freeze, then the mass of water transpired may be relatively large. For instance, at 5:30 A.M. near Indio, California, on January 14, 1963, the air temperature was 19.4° F, leaf temperature 18.6° F, and the temperature of the dew point 12.0° F for a relative humidity of 72 per cent. When these values are substituted in equation (12) for one meter² of wet outer surface using leaf external surface rather than internal surface, the mass of water evaporated per hour is sizeable (3.18×10^{-4} gm), as compared with a warmer night having a higher dew point of 30.4° F (RH = 98 per cent), air temperature of 30.6° F, and leaf temperature of 30.3° F, for which m can be calculated to be 0.52×10^{-4} gm. Leaf temperature is also lower than air temperature in the latter case and as a result condensation occurs. In the former case, the low water vapor pressure of the air was more effective in increasing evaporation than the temperature. This

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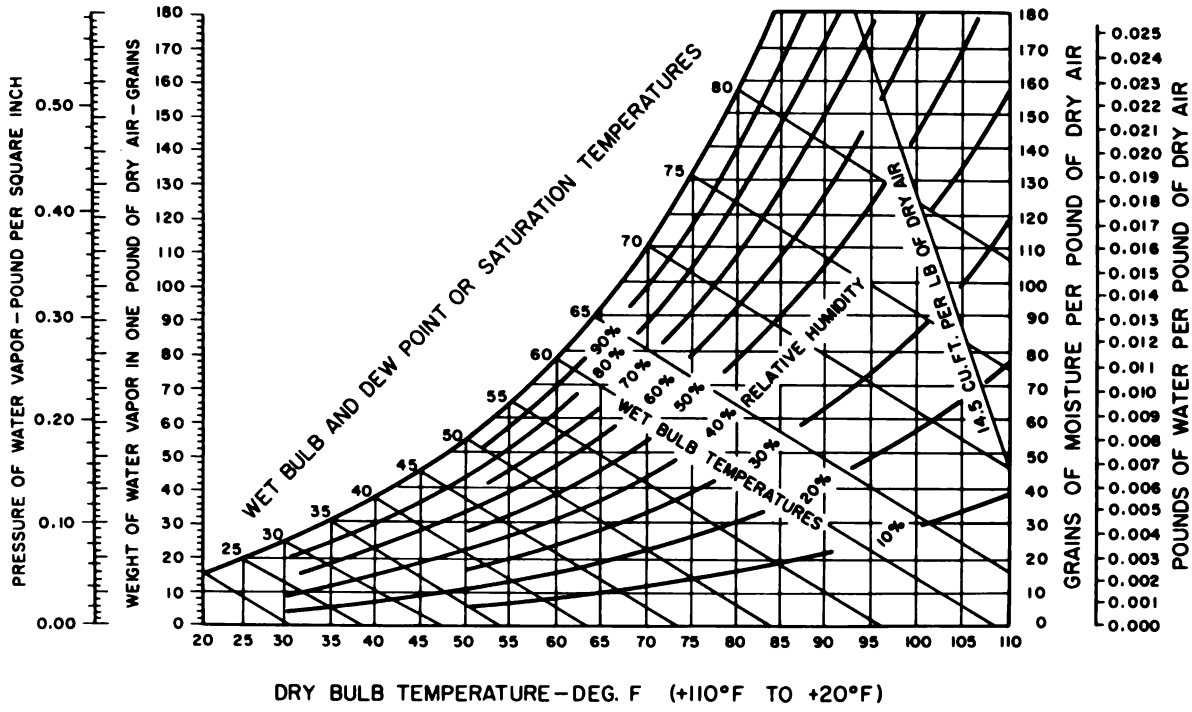
PRESSURE OF WATER VAPOR – POUND PER SQUARE INCH
WEIGHT OF WATER VAPOR IN ONE POUND OF DRY AIR – GRAINS
WET BULB AND DEW POINT OR SATURATION TEMPERATURES
RELATIVE HUMIDITY
WET BULB TEMPERATURES
14.5 CU. FT. PER LB. OF DRY AIR
GRAINS OF MOISTURE PER POUND OF DRY AIR
POUNDS OF WATER PER POUND OF DRY AIR
DRY BULB TEMPERATURE – DEG. F (+110°F TO +20°F)
PSYCHROMETRIC CHART – MEDIUM TEMPERATURES. BAROMETRIC PRESSURE, 29.92 in. Hg

Fig. 10–53. Temperature of dew point plotted against per cent relative humidity for medium to freezing air temperatures (dry bulb) with scales for converting water vapor per pound of dry air (in grains) to vapor pressure. (After Psychrometric Charts, courtesy of EG&G Inc. and GE.)

situation was recognized by Cooper *et al.* (1963*a*), who reported that citrus leaves during the Florida freeze appeared freeze-dried, and Miller (1963*b*) who reported that citrus leaves under sprinklers in California were 3.2° F to 4.8° F colder than air temperature. This may be visualized from figure 10–53, and the heat lost by evaporation may be calculated readily from equation (11). The heat lost by Miller's wet leaves was 2.15×10^{-1} cal/cm² sec °C as compared with 1.04×10^{-4} cal/cm² sec °C for the dry leaf, neglecting radiation and free convection losses.

Normally heat loss by evaporation (transpiration) for leaves is low at night and even lower on a cold night ranging from 0.309 to 0.315×10^{-4} cal/cm² sec °C (Turrell, Austin, and Perry, 1962), but Turrell and Austin (unpublished) have shown that transpiration losses by fruit or by wood, unlike leaves, is not curtailed at night because of inoperative stomata in the former case and the presence of lenticels in the latter. Thus transpirational cooling at night is relatively larger for fruit and wood than for leaves.

Thermal Conductivity

Heat transfer from one part of a body to another is termed conduction. There is no extended motion of the parts. It may occur in gases, liquids, or solids, but thermal conduction in solids is the most commonly and easily observed phenomenon. Citrus fruit and wood if heated unilaterally by the sun become warm throughout. If cooled on one side at night, heat is transferred from the warmer side to the colder. During frosts and freezes, thermal conductivity may play a critical role in the heat budget of a grove. The soil one foot below the surface may have a nearly constant temperature of around 55° F in winter in certain southern California citrus-growing areas (see chap. 9). As previously mentioned, if the soil surface is dry, heat from below passes through the surface at a very slow rate, because air, which is a very poor conductor of heat fills the pores ($k_{air} = 5.80 \times 10^{-5}$ at 0° C and $k_{water} = 1.32 \times 10^{-3}$ at 0° C; $k_{ice} = 5.35 \times 10^{-3}$ cal/cm^{-2} sec^{-1} °C^{-1} cm at –10° C). In a good conducter such as copper, the thermal conductivity coefficient, k, is about one cal/

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cm^{-2} sec^{-1} $°C^{-1}/cm$. The thermal conductivity (k) of fresh citrus wood is 1.415×10^{-3} cal cm^{-2} sec^{-1} $°C^{-1}/cm$ perpendicular to the axis according to Turrell, Austin, McNee, and Park (1967) and 0.980×10^{-3} perpendicular to the axis. Thus even in a living tree filled with water, as citrus seems to be, the tree is a poor conductor of heat, falling between water and air. However, it is on thermal conductivity that two methods of frost protection depend: the self-protection of large trees and the use of tree wraps for small trees. In the latter case, the tree wrap should have a low conductivity and a high volumetric heat capacity.

Thermal conductivity also plays an important role in the freezing of fruit. Citrus fruit are poor conductors of heat (Gane, 1936; Poppendiek, 1953; Turrell and Perry, 1957; and Perry, Turrell, and Austin, 1964), and coefficients of conductivities range from 0.78 to 1.17 cal/cm^{-2} sec^{-1} $°C^{-1}$ per cm. It may be calculated that a small fruit can go through a sudden 50° C temperature change in fifteen minutes while large fruits may require one to two hours. Thus large fruits may coast through sharp temperature drops which are of short duration during the night without freezing. The peel of the fruit has approximately one half the thermal conductivity of the pulp, according to measurements made by Turrell and Austin (1969), although Shiftan (1945) found their thermal conductivity about the same.

There are two types of thermal conduction (process of energy transition). These are (1) "steady-state" in which a solid body receives a constant supply of heat (energy in transition) at one surface and loses it at the same rate from another surface, and (2) the "transient or unsteady state" in which the heat supply is variable and the rate of heat loss is variable. It is this latter type of conduction which occurs in the tree. The conduction of heat in dielectric (nonmetallic) substances such as wood, fruit, and leaves is affected by lattice waves and free electrons. However, basically, the driving force is the same in both types. Steady-state rate of heat transfer is expressed by an equation developed by Fourier,

$$Q = kA\,\Theta\,\frac{(t_1 - t_2)}{d} \qquad (13)$$

when Q = cal, k = the thermal conductivity in cal cm^{-2} sec^{-1} °C per cm, A = surface area in cm^2, t = temperature in °C, θ = time in seconds, and d is the distance through the conducting medium in cm. This equation shows that the driving force in thermal conduction is the temperature gradient and k is a proportionality constant which is one of the principal thermal properties of the material. The most important of these properties are c_p, the specific heat, and ρ, the density. Where α is designated as the thermal diffusivity, these relationships are expressed best by the equation

$$\alpha = k/\rho\, c_p \qquad (14)$$

α having the dimensions, length^2/time.

The above equations, which are for steady-state, one-dimensional heat transfer, where the temperature at a given point is independent of time, can be applied to roots below the one foot level in making comparisons for short periods. The diurnal temperature fluctuations are small, but the seasonal ones are not. Obviously, nearly steady-state heat transfer prevails generally only in underground parts, the transient-state existing above ground (see figs. 10–56 and 10–57, pp. 422, 423).

Thermal Conductivity for the Unsteady State

Consider the temperatures throughout a 20-foot tree in still air during a twenty-four hour period. The trunk (cylindrical, ϕ = 50.4 cm; fig. 10–54, *A*), the limbs (conical solid, ϕ = 2.5 to 10.5 cm; fig. 10–54, *A*), the fruit (spheres; fig. 10–54, *B*, *C*), the leaves (plates; fig. 10–54, *D*), and the roots (cones; fig. 10–54, *E*) are all exposed to an array of different changing temperatures because each portion of the tree responds with a different mean temperature and a cycle of temperatures of varying amplitude about this mean. During daylight, solar radiation makes the soil surface warmest, and soil and air temperatures vary inversely with distance from the surface. At night, the soil surface is coldest, and soil and air temperatures vary directly with distance from the soil surface (fig. 10–54, *E*, *F*). Each organ may have a different mean temperature and cycle of temperatures of varying amplitudes depending on size, shape, k, ρ, moisture content, mass, structural symmetry, and emissivity of the surface.

Analytical solutions are available for the unsteady state, (Williamson and Adams, 1919; MacLean, 1930, 1946), but the equations are complex and graphical methods have been developed by various authors (Gurney and Lurie, 1923; Olson and Jackson, 1942; Patton, 1944; Jacob, 1949, 1957; and Perry and Berggren, 1944). Steady-state equations for spheroids and cone segments are also complex (Niven, 1880; Datta, 1918; Carslaw, 1945), but transient-state equations for spheroids and cone segments are indeed

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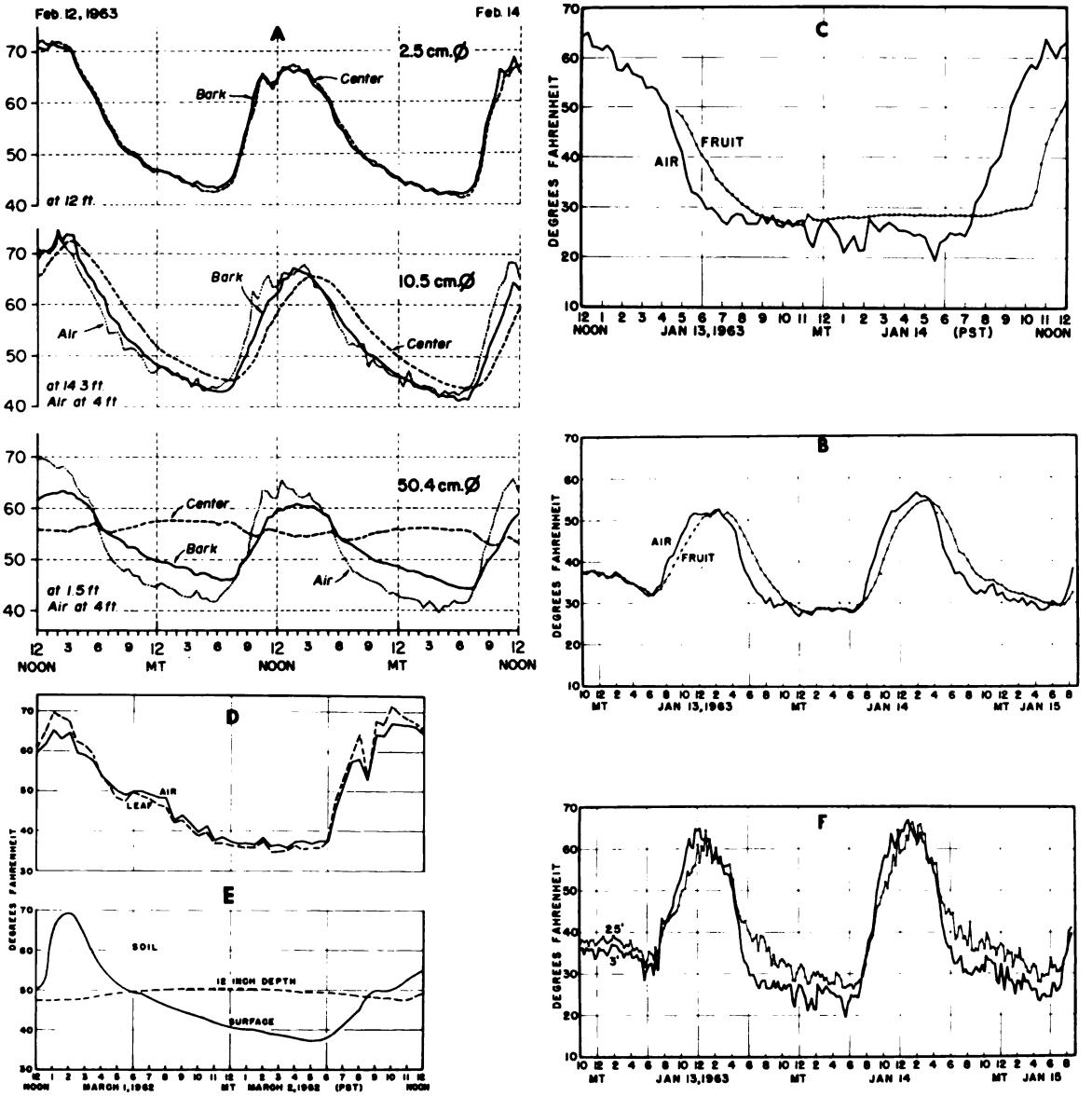

Fig. 10–54. Automatically recorded air, soil, and citrus tree temperatures obtained with thermocouples in the orchard for 12- and 24-hour periods. *A*, temperatures in center of small branches 2.5 cm in diameter (ϕ) are the same as for bark during the diurnal cycle. Branch was 12 feet above ground. Branch center, air, and branch bark temperatures of large branches (ϕ = 10.5 cm) 14.3 feet above ground are all out of phase. Trunk-center (ϕ = 50.4 cm), trunk bark, and air temperatures are further out of phase than in small limbs, and center temperatures are highest from midnight to 6 a.m. *B*, air and grapefruit center temperatures at 4 feet above ground in an orchard of 28-foot-tall trees at Indio, California, which has a desert climate. The grapefruit was oblate (ϕ_a = 7.68 cm, ϕ_b = 7.13 cm) and inside the tree, protected from the sky. Its center temperature lagged air temperature from 1 to 2 hours, and did not show rapid fluctuations as did the air. *C*, air and grapefruit-center temperatures at 3 feet above ground in an open area (adjacent to *B*) in a one-year-old, four-foot-tall tree. Fruit was oblate (ϕ_a = 7.5 cm, ϕ_b = 7.25 cm), not exposed to sky, lagged air temperature 1 to 2 hours, and was warmer than air temperature until 7 a.m. *D*, air and lemon leaf temperatures at 10 feet above ground in an orchard of 12-foot-tall lemon trees at Ventura, California, which has a coastal climate. The leaf was exposed to sky and 1° F to 2° F below air temperature from 4 p.m. to 6 a.m., changing temperature instantaneously with air temperature. *E*, soil temperatures between lemon trees in same Ventura orchard as shown in *D*. Soil surface temperatures reached maximum at 2 p.m. minimum at 5:30 a.m. At 12 inches below surface, maximum was reached about midnight, minimum at 11 a.m. *F*, air temperatures at 3 and 25 feet above ground in an open area at Indio, showing higher temperatures near ground during day and lower temperatures from sunrise to sunset.

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even more complex and appear not to have been worked out to date. However, they will undoubtedly soon be available. Electronic computers and the treatise on heat-transfer calculations by Dusinberre (1961) will be helpful.

Heat Storage of Plant Tissues

Leaves, fruit, and branches store heat during the day as a result of irradiation by the sun. In small trees, the amount of storage is small because the total mass of each of the three types of organs is low. On a cold night, small trees would be expected to give up the heat stored during the previous day rather quickly. But in very large citrus trees, such as a 40-year-old grapefruit tree, the total mass of fresh leaves might amount to between 2×10^5 and 1×10^6 grams, the weight of fruit might total in the neighborhood of 1×10^6 grams, and the fresh weight of the woody frame (trunk and branches) might weigh 2.25×10^6 to 6.25×10^6 grams (Turrell and Austin, 1965). Obviously, the amount of heat stored by a fruit tree which is largely water (i.e., more than one-half) is very large and this will influence frost control methods required. The heat stored can be calculated from the basic equation of heat storage:

$$q = \rho \; c_p V \frac{\Delta t}{\Delta \Theta} \qquad (14)$$

where q = heat energy stored per unit time, ρ = density, c_p = specific heat, V = volume, Δt = temperature change, and $\Delta\theta$ = time interval. It can be seen from this equation that if the comparative amount of heat lost per unit time at night, or the temperature attained at a given time at night by large and small trees are to be found, some specific scale of temperature comparison must be adopted. Turrell and Austin (1965) have suggested that H_s be chosen to designate specific enthalpy or the amount of heat gained or lost by the tree for a 1° C change in environmental air temperature.

Heat Storage of Water

The capacity of water to store heat is the greatest of any commonly known substance, and thus its specific heat (c_p) is taken at 1.000. Since a gram calorie of heat is defined as the amount of heat required to raise one gram of water 1° C, at 4° C, it can be seen that cooling 1 gram of water 1° C will yield one calorie of heat. Thus irrigation with warm well water is an excellent method of emergency frost protection. The greater the amount and the warmer the water applied, the greater the amount of frost protection. Drainage, however, must be good to prevent root damage by water-logging the soil. High moisture concentration in the air also has several heat-conserving effects in preventing frost damage. If moisture concentration in the air is only present in a thin layer near the ground, such as might be held between the trees, evaporation from soil and transpiration from plants are reduced. If the concentration is in a thick layer, radiation losses to space will be lower because of absorption.

Atmospheric Moisture

Frost and freeze damage to plants is, first of all, a result of heat transfer from the plant. So far, equations have been given which make it possible to quantitatively evaluate the various modes of heat transfer affecting the plant. Now, we shall need to consider the interaction of the modes of heat transfer in the plant, and between these in the plant and ground, the plant and air, the plant and sky. To evaluate these modes of interaction, heat transfer of the elements of the plant's environment must be known, plus the heat exchange between the ground and air, between the ground and sky, as well as the inter-

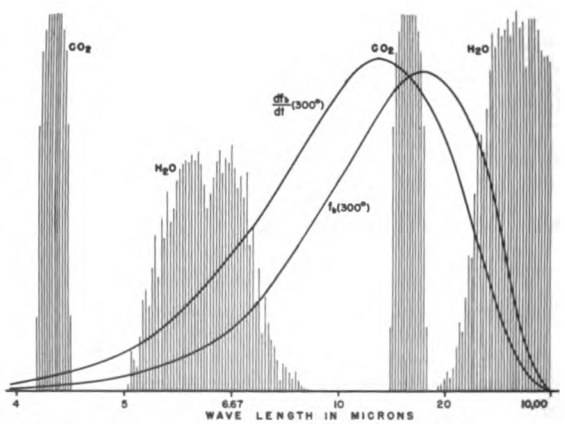

Fig. 10–55. Infrared spectrum of the atmosphere, showing absorption bands of water vapor and CO_2 from 4 μ to 1000 μ plotted as wave number ($\nu = \frac{1}{\lambda}$) and the commonly used integrated intensity ($\int f_b d\nu$) over a specific interval between limits of O and x, upper curve; and below, a curve f_b (300°), which is plotted as the wave number (cm^{-1}) and the total emission of a black surface, in degrees Kelvin, into the hemisphere. Note the peak change of the upper curve to 12 μ which compares with 9.7 μ in a normal micron plot (Elsasser, 1942).

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action of the modes of heat transfer of ground and air and sky. Water, in the vapor phase, is one of the most important components of these heat transfer systems.

The moisture content of the air influences radiation of heat from the ground and from the plant to space. Water vapor in the atmosphere absorbs infrared radiation from the ground, from plants which cover it, and from other objects on the earth's surface. It absorbs between 1.2 and 6.3 μ in bands at 1.37, 1.84, and 2.66 μ with a transparent region ("window") from 3.5 to 4.5 μ. There is an intense absorption band at 6.26 μ, incomplete absorption at 7.0 to 8.5 μ, another transparent region from 8.5 to 11.0 μ, and absorption on out to 100 μ. The most important regions of this spectrum are shown in figure 10–55 and it may be surmised that the depth of the absorption bands would be increased by an increase in water vapor content of the air or decreased by a lowering of the water vapor content of the air. If sufficient water vapor was present to condense and make fog or clouds, the absorption of radiation would be increased. Fog and clouds are grey bodies and not spectral radiators like water vapor. A cloud 10 to 30 m thick would stop 99 per cent of the loss to space. In California, the Fruit-Frost Service reports dew points measured at 2 P.M. Thus, the dew points are determined usually at air temperatures of 60 to 80° F. The relationship of relative humidity to dew point was shown in figure 10–53. A relative humidity of 100 per cent corresponds to a dew point of 0° C when the air and vapor temperature is 0° C (vapor pressure = 4.58 mm Hg or 6.09 millibars (mb), since 1 mm Hg equals 1.333 millibars and 1 mb equals 0.7501 mm Hg (List, 1966). A relative humidity of 25 per cent corresponds to a dew point of –15° C based on saturated air at 0° (vapor pressure = 1.38 mm Hg = 1.84 mb). When the relative humidity reaches 100 per cent the skies may become cloudy and a warm night would result if the air were calm. Nearly all the radiation leaving the ground and plants may be absorbed by the water vapor in the atmosphere when the concentration and depth are great enough. Under maximum conditions, three quarters of the absorbed radiation is reradiated back to earth. These depths may extend to the stratosphere, but a cloud of about 165 feet in thickness (50 meters) will absorb nearly all terrestrial radiation and radiate as a black body. A careful comparison has been made of the absorption by water vapor, clouds, etc., by De Boer (1965). This is based on the absorption coefficient of liquid water. Thus a cloud of this thickness will absorb all the long-wave radiation (Berry, Bollay, and Beers, 1945). The ratio ($R/\sigma T^4$) of downcoming radiation (back radiation = R) to the outgoing radiation (σT^4) is about 0.76 at 100 per cent relative humidity as compared with 0.67 at 25 per cent (Appendix III, figure III–1, p. 506). At the same time, the cooling power of the sky as shown in Appendix III, figure III–2, p. 507, indicates the net radiation ratio

$$\text{"}r\text{"} = \frac{\text{(outgoing radiation – total radiation)}}{\text{(outgoing radiation)}}$$ is 0.244 at 100 per cent relative humidity and 0.337 at 25 per cent.

Irrigation

Irrigation water from wells or other sources may be relatively warm (usually above 60° F in the subtropics) and have some utility for frost protection. At 70° F (21° C) and a rate of 1 inch (2.54 cm) of application per cm^2 of soil surface, when irrigation water cools to 32° F (0° C), the yield is 2.54 × 21.0, which equals 53.34 calories of heat. The net rate of heat loss from ground surface on a cold clear night might be 0.00175 gm cal cm^{-2} sec^{-1} or 6.3 gm cal cm^{-2} hr^{-1}. If the temperature of the water surface was the mean of the air and water temperature then $\frac{21° + 0°\text{ C}}{2}$ = 10.5° C and Q, the amount of heat that would be available to flow to a 1 cm surface from 2.54 cm depth of water is 26.7 gm cal cm^{-2} sec^{-1} or 9.61 × 10^4 gm cal cm^{-2} hr^{-1} which is many times the rate needed to meet the demands of the sky. But if the irrigation water froze completely, then nearly four times as much heat would be released as in the cooling process. For example, the water comprising a rectangular right prism would weigh 2.54 gm ($m = V\rho$ = 1 cm^2 × 2.54 cm × 0.9998 gm/cm^3), and the amount of heat released would be 202.4 gm cal ($Q = mL_f$ = 2.54 gm × 79.7 gm cal/gm).* The limiting factor again is thermal conductivity, but k is four times larger for ice. This clearly shows that the application of irrigation water can supply a great deal of heat to an orchard because of the water's high heat capacity, especially when the change of phase occurs and it freezes.

* L_f = latent heat of fusion of water (List, 1966).

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STATE OF THE ATMOSPHERE

The warming of the ground, and consequently the atmosphere, by bright sunlight following nights of frost is characteristic and advantageous to southern California citrus districts. Freezes, however, are often accompanied by cloudy-day skies. The usual warming of the ground during the day does not take place, minimum night temperatures are lower, and the duration of low nocturnal temperatures is greater. The amount of sunlight received (in percentage of clear day value) on a cloudy day (cloud in tenths) as compared with a normal day can be calculated with a linear equation (Fritz, 1957).

Table 10–16
SOLAR RADIATION FOR THE FREEZE OF JANUARY, 1937 AT RIVERSIDE, CALIFORNIA

Dates in January, 1937	Sky	Solar Radiation (Gm-Cal/Cm²/Hr) Morning Hours of Day A.M. 7–8	8–9	9–10	10–11	11–12	12–1
7*	Clear	3.0	15.0	30.9	40.0	45.0	30.0
8*	Clear	3.0	20.0	33.0	42.0	46.0	47.0
9*	Clear	2.0	5.0	30.0	41.0	45.0	46.0
10*	Clear	4.0	19.0	31.0	42.0	47.0	46.0
11†	Clear	2.0	6.0	34.0	43.0	47.0	48.0
12	Cloud/Rain	1.0	8.0	14.0	19.0	15.0	10.0
13	Cloud/Rain	1.0	10.0	12.0	25.0	20.0	24.0
14	Cloud	1.0	5.0	16.0	22.0	24.0	15.0
15	Clear	5.5	21.0	35.4	43.6	49.0	49.8
19	Part/Cloud	.....	.....	.....	.....	.....	.....
20*†	Clear/Cloud	1.2	3.2	24.4	31.2	38.2	33.4
21*	Clear/Cloud	2.7	11.0	33.6	40.7	34.7	45.3
22*†	Clear	1.6	6.5	23.0	25.1	24.4	24.4
23*†	Clear	1.4	6.3	32.2	26.6	39.1	25.5
24*	Cloud	0.2	3.8	10.8	11.3	13.1	23.9
25*	Clear/Cloud	3.9	17.3	32.4	41.9	48.7	49.6
26*	Clear	.....	.....	.....	.....	.....	.....

Dates in January, 1937	Sky	Afternoon Hours of Day (Gm-Cal/Cm²/Hr) P.M. 1–2	2–3	3–4	4–5	5–6	Total Solar Radiation	Solar Radiation (Per Cent)
7*	Cloud	20.0	15.0	12.0	1.0	.....	211.0	68.1
8*	Clear/Cloud	40.0	30.0	16.0	4.0	.....	281.0	90.6
9*	Clear	41.0	31.0	15.0	3.0	.....	259.0	83.5
10*	Clear	42.0	33.0	18.0	4.0	0.2	286.2	92.3
11†	Clear	44.0	34.0	19.0	3.0	.....	280.0	90.3
12	Cloud/Rain	12.0	11.0	7.0	1.0	Windy	98.0	31.6
13	Cloud/Rain	28.0	20.0	15.0	4.0	.....	159.0	51.3
14	Cloud	11.0	10.0	6.0	1.0	.....	111.0	35.8
15	Clear	45.2	35.0	21.0	5.2	.....	310.0	100.0
19	Cloud	.....	.....	.....	.....	.....	.....	.....
20†	Clear/Cloud	17.0	17.3	7.4	1.8	.....	175.1	56.5
21*	Clear	49.7	37.0	22.8	5.8	0.2	283.5	91.5
22†	Cloud	21.9	12.2	6.2	2.1	.....	147.6	47.6
23†	Clear	8.4	7.8	3.0	1.2	.....	151.5	48.9
24*	Cloud	26.9	11.0	5.7	1.2	.....	107.9	34.8
25*	Clear	43.5	33.3	19.6	5.0	.....	295.3	95.3
26*	Clear	.....	.....	.....	.....	.....	.....	.....

Source: Record on file at the Citrus Research Center and Agricultural Experiment Station, University of California, Riverside, California. Also see Jones, Garber, and Newman (1966).

* Smudge.

† Heavy smudge.

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When cloudiness is greater or less than normal, Hembree (1958) found the equation for an ellipse gave a better fit:

$$Y = 1.18\left(\sqrt{1 - \frac{(X + 0.3)^2}{(1.4)^2}}\right) - 0.15 \qquad (15)$$

where Y equals the fraction of clear-day insolation received and X equals the fraction of the sky covered with clouds. Eccentricity varies with locality. Smoke acts in a manner similar to clouds in reducing sunlight intensity.

The severity of the "text-book" 1937 freeze in southern California was attributed in part to the prevention of normal daytime solar heating of the ground by heavy smoke from orchard heaters.* This may have been true in the lower districts after the wind had died down, since it reduced the possible 10 hours of sunshine in the districts of lower altitude by an amount varying from 83 per cent to 16 per cent on five different days. Illumination conditions were less severe at the Citrus Research Center, Riverside, California, at an altitude of 1,050 feet, as shown in table 10–16. Solar radiation, however, even at this altitude was reduced by 68 per cent on January 12, but this was a windy day as shown in table 10–17, and the lack of sunshine was not a result of smoke in the atmosphere. The daily amount of solar radiation was generally low in January because of rain and daytime cloudiness (table 10–16). Williams (1964) has shown that smoke accumulates in the Salt Lake Valley when a "high" stagnates in the Great Basin. He has shown that instability, high winds, or precipitation clear the smoke very quickly. It must be conceded however, that the ground was cold throughout January, 1937, as a result of rains, cloudy weather, and smudge. There were only fourteen insolating days during the month.

The meteorological factors in citrus-growing areas seem to be very much in favor of freezes being "dry." Very cold air loses its moisture in the cooling process. The colder the air mass, the lower its water content, and the dryer the air, the poorer its power of absorption of terrestrial infrared radiation. Thus, very cold air, whether moving or still, in thin or thick layers (freezes are in thick layers) produce the lowest freezing temperatures.

Many warnings have been given concerning the greater danger of damp freezes (Horn, 1937; Young, 1949; Adams, 1952). There appears to be little published evidence to support their greater severity, and any evidence must be assumed to be largely observational. The belief in severity of such freezes appears to relate to plant response rather than meteorology. This suggests that warnings about such freezes apply to peel damage primarily (Young, 1951), such as waterspot and water-rot, which result from rains either before or after the freeze. Young (1951) states, however, that such damage is of infrequent occurrence (Peynado, Young, and Cooper, 1963). And, although Young (1941) and Lucas (1954) noted that less supercooling occurs in lemons when the surface is wet or ice coated, the low temperatures necessary to freeze the pulp under meteorologically wet conditions are relatively rare. Most freezes in California, including the 1963 freeze, have been accompanied by very dry air in the atmosphere. Recent freezes in Florida, Texas, Arizona, and Mexico have likewise been accompanied by air having a very low dew point (Young, 1963*a*; Peynado, Young, and Cooper, 1963; Cooper, Hearn, Rasmussen, and Young, 1963*a*; and Stugard and Burke, 1962).

STATE OF THE GROUND

The state of the ground in the path of air mass movement is important in determining minimum air temperatures during freezes. Freezes are more severe when the air mass moves across dry ground as was the case in the Central Valley of California during the 1963 freeze. Northern California and Oregon were very dry prior to the freeze. This was also true in Texas in the 1962 and 1963 freezes (Young, 1963*a*) and in Florida in December, 1962, and January, 1963 (Johnson, 1963). Heat stored in the soil depth reached the surface very slowly due to the insulating effect of the dry upper soil layer. Freeze years are those in which the air mass traverses more extensive snow and ice fields, becoming very cold coincidentally with a strong northwesterly flow of air in the upper atmosphere (Johnson, 1963).

Soil Moisture

The amount of moisture in the soil determines the degree of warming and storage of the sun's heat during the day and its transfer to the

* Smoke absorbs solar radiation according to Beer's law where I = the solar intensity in a smoky atmosphere; I_o = solar intensity on a clear day; e = base of natural logarithims; c = concentration of smoke, (a) as measured by the visibility (Williams, 1964), or (b) solar radiation at the earth's surface (Stern, 1962), d = thickness of the smoke layer, and k = constant. The equation is thus $I = I_o e^{-kcd}$.

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Table 10–17
WIND DIRECTION AND WIND SPEED FOR THE 1937 FREEZE IN RIVERSIDE, CALIFORNIA

Dates for January, 1937	Wind Direction and Wind Speed (Mph)											
	A.M.	*Morning Hours of Day*										*Noon*
	12–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12
7°	W-SW-E	E-N	N	N	N	N	N	NE	SE	SE	SE	SE
	1	2	9	9	13	9	5	7	3	4	6	6
8°	NE	NE	N	N	N	N	NNE	NNE	NNE	N	N	N
	10	10	12	15	9	9	9	9	11	12	12	15
9°	N	N-E	E-N-NE	N-SE-N	N-E-E	E	E	E	E-NE	N	N	N
	10	8	6	7	6	3	3	3	6	6	5	4
10°	E	E	SE-NE-E	E-S-E	E	NE	NE	NE-S-NE	NE-S	NE	NE	NE
	8	5	3	3	6	4	6	6	4	4	9	9
11	E	E	E	E	E	E	E	E	E-S-NW	S	S	S
	3	3	5	6	4	5	4	2	3	3	3	5
12	W-E-E	E-E-N	N-N-E	SE	SE	SE	SE	SE	SE-SE-NW	SE	SE	SE
	1	4	2	3	8	7	10	10	4	1	3	3
13	SE	SE	NW-SE	SE	NW-SW-NW-W	NW-SE	NW-SE-SE	SE	SE	SE	SE	S
	2	3	4	7	3	2	6	7	7	6	4	1
14	SE-E-NW	SE-NE	SE	SE	NW-SE-NW	SW	SE	SE	SE-NW-SE	NW	NW-SE	SE-NW
	4	2	7	5	2	2	2	3	4	2	3	2
15	N-E-E	E-NW-E	E	E-S-E	E	E	E	E	E	NE	N	SE-NE-NW
	3	2	1	2	2	2	4	4	6	3	2	2
20°	N	N-SE	E	E	N-SE-NE	E	NW	E	E	N	N	N
	1	1	1	3	2	2	1	1	2	6	9	9
21°	N	N	N	N	N	N	NNE	NE	NE	N	N	N
	15	18	19	18	20	14	10	10	14	13	16	17
22°	E	SE-NE	NE-E	E	E	E	E-N-E	E	E	SE-N-SE	SE	SE-W
	5	3	4	3	2	2	2	3	2	2	6	6
23°	NE	NE	NE	NE	E	E	E-NE-SE	E	E	NE-E-SE	SE	SE
	8	7	11	7	5	2	4	2	5	5	6	6
24°	N-E	E	E	E	E	E-N	NE-E	N	SW-E	NW-S-W-N	E	SE
	1	1	1	1	1	1	2	2	1	2	2	4
25°	....	....	....	....	....	....	....	....	....	E-S-W	NE	N-SE
										1	3	4

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	Noon	*Afternoon Hours of Day*								P.M.	
	12–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12
7°	SE	SE	SE-SW	SW	SW	SE	SE	SE	N-NE	NE	N	N
	5	6	6	8	5	1	2	2	10	12	14	10
8°	N	N	N	N	N	N	N	N	N	N	N	N
	15	18	21	19	20	18	17	13	17	10	12	12
9°	SE-NE	N	N	N	NE	NE	E	NE	E	E	E	NE
	4	7	9	10	6	7	6	8	5	5	6	9
10°	NE	NE	NE-N	N	NE	S-W-NE	S-NE	S	E	E	E	E
	8	8	9	8	8	3	3	3	2	2	2	2
11	SE	SE	S	SW	W-S	S-E-E	E	E	E	E-SE-E	E-W-W	W
	4	4	3	4	3	1	2	4	2	1	1	0
12	SE	SE	SE	SW-SE	SE-SW-S	E	E-SE	SE	N-E-SE	SE-SE-NW	SW-NE	E-S
	9	7	8	5	10	3	3	2	6	4	7	1
13	NE	NW-SW-NW	NW-NE	NW-NE	NE-N-NW	W	E	E	E	E	E-SE	SE
	2	4	3	3	1	1	2	4	3	2	2	5
14	NW	W	SW	SW	SW	SW-E	E	E	E	E-E-S	S-E-E	N-S-E
	2	2	1	0	2	2	4	3	2	3	2	1
15	NW-SW-S	NE-SW	SW-NW-SW	W	W-W-SW	SW-E	E	E	E	E	E	E
	2	2	4	3	2	2	2	3	3	3	3	3
20°	N	N	N	N	N	N	N-NE	NE	N	N	N	N
	13	14	15	14	12	12	8	9	9	8	11	13
21°	N	N	N	N	N-NW	SW	SW-NW-N	N	N	N	N-NE-SE	SE-SW-SE
	23	27	21	19	11	5	6	15	11	9	6	2
22°	NW	N	N	N	N	N	N	N	N	NE	E	E-NE
	4	9	8	11	10	8	9	10	7	8	4	3
23°	S	SE	SE-NW-W	W-E	E	E	E	E	E	E-W	NW-NE-N	N-N-NW
	3	3	2	2	3	4	4	4	2	1	3	2
24°	....	....	....	....	....	....	....	....	....	....	....	....
25°	SE	SE	SE	SE	SE	NW-E	E	E	E	SE-SW-E	SE	N-SE-SE
	6	6	7	7	4	2	2	2	2	2	2	2

Source: Data on file at the Citrus Research Center and Agricultural Experiment Station, University of California, Riverside.
° According to Young (1938*b*), these are freeze dates.

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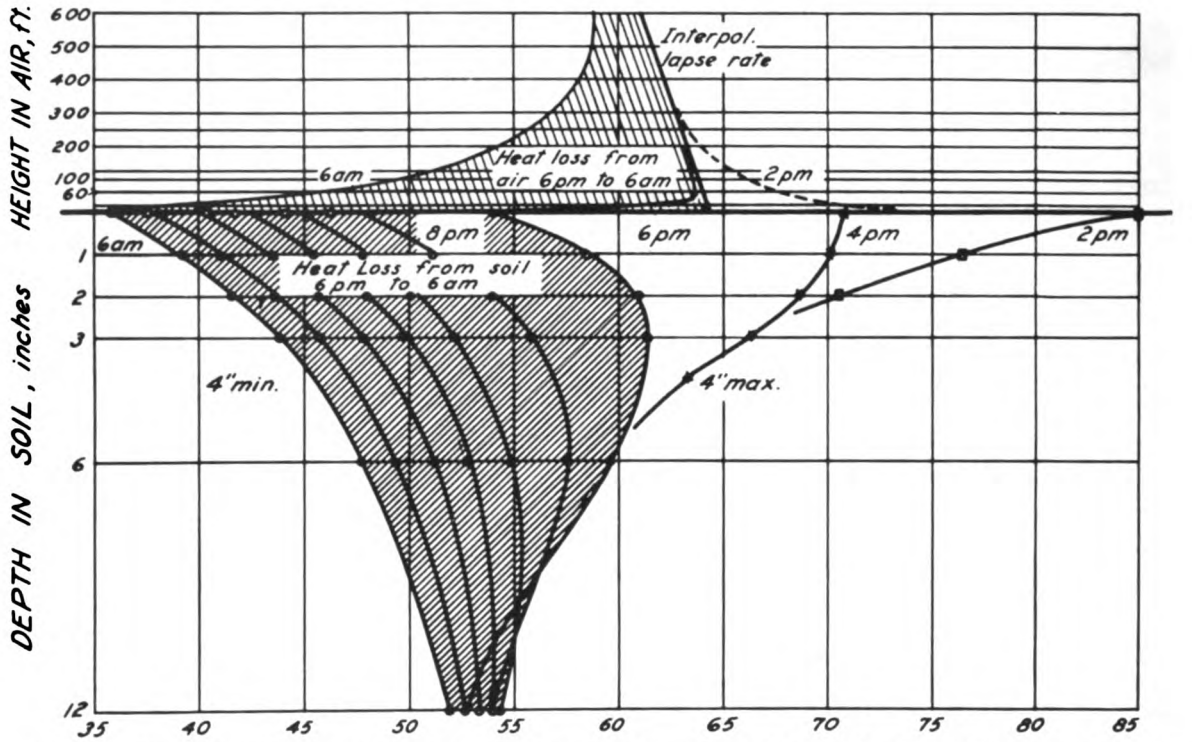

Fig. 10–56. Observed nocturnal soil temperature profiles in degrees Fahrenheit at Riverside, California, on February 24, 1939. (Brooks, 1957.)

surface at night. This temperature change for varying depths is shown in figures 10–56 and 10–57. Berry, Bollay, and Beers (1945) state that "the terrestrial flux indicates that nocturnal variation in temperature depends on the type of ground, because of density, specific heat, and specific conductivity." The state of the ground is thus partially dependent on soil type, including soil color. Neiburger (1941) has developed equations by which calculations of daily maximum air temperatures in California could be made from the solar energy received at the ground.

Hembree (1958) showed that when the ground surface is covered with snow or slush, heavy frost (or is frozen), or puddles, and is wet or dry, for the same weather conditions, air temperature near the ground may vary 4° F or more because of differences in heat absorption of these surfaces. He also showed that the state of the ground during a winter month is reflected in the deviation of the mean of the ratio of $\frac{\text{ground absorption}}{\text{insolation}}$. At Nashville, Tennessee, these deviations were +5 per cent for November, +10 per cent for December, +5 per cent for January, and 0 per cent for February. The state of the ground acts independently on three heat transfer components to disturb the energy balance, RI_o, LE, and S, where I_o = the total incident solar radiation per unit surface, R = surface albedo, B_o = the net longwave radiation (positive upward), E = the amount of water evaporated and/or transpired, L = the latent heat of evaporation, S = the heat used in raising the temperature of the ground, and H_o = the heat available from the ground surface to raise the temperature of the lower atmosphere, in the local energy balance at the ground as indicated in the equation

$$I_o = RI_o + B_o + LE + S + H_o, \qquad (16)$$

and where ϕ is the energy not available to the air of the heated layer

$$\phi = I_o - H_o \qquad (17)$$

or

$$\phi = RI_o + B_o + LE + S. \qquad (18)$$

If H_a, in Langleys (cal/çm²), is the quantity of heat used in heating a layer of air from an initial mean temperature $\bar{T}_o$ to $\bar{T}_x$, the maximum afternoon temperature

$$H_a = 0.1372(p_o - p_x)(\bar{T}_x - \bar{T}_o), \qquad (19)$$

where $\bar{T}_x$ and $\bar{T}_o$ in °F are determined from an emagram, and p_o is the surface pressure and p_x is the pressure at the top of the layer affected by

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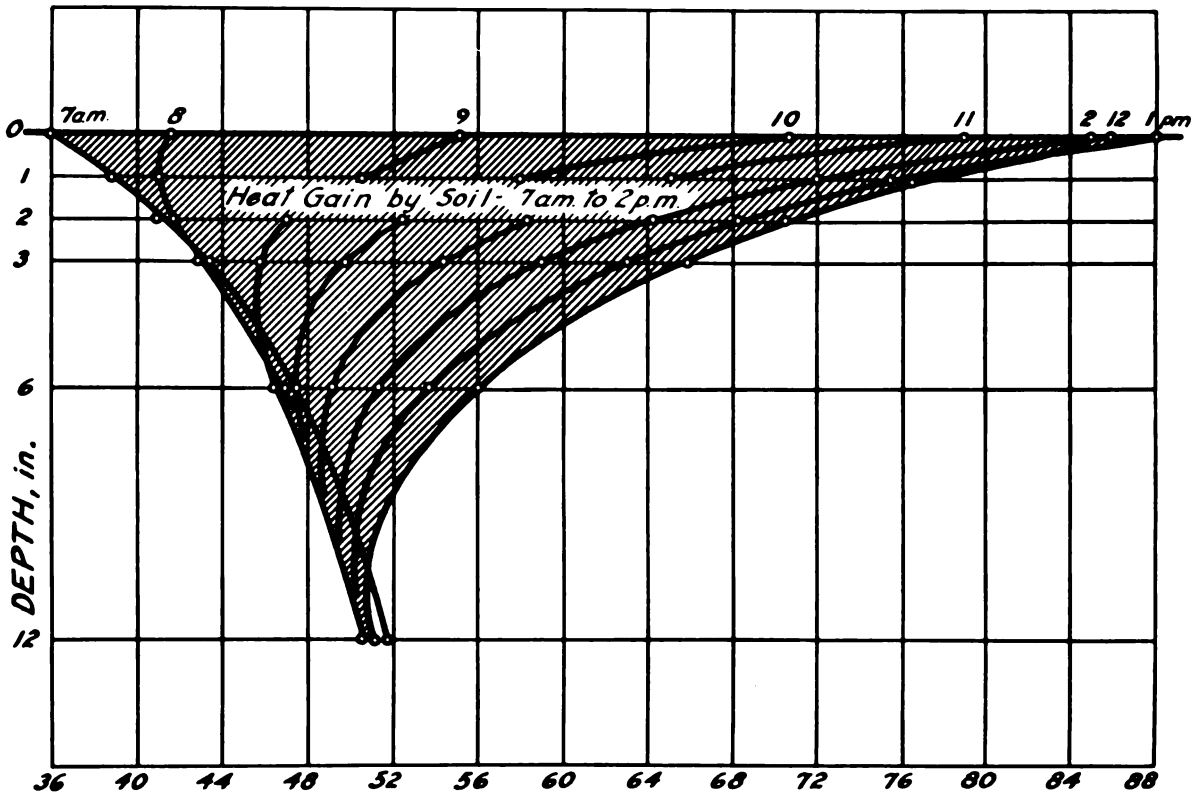

Fig. 10–57. Observed daytime soil temperature profiles in degrees Fahrenheit at Riverside, California, on February 24, 1939. (Brooks, 1957.)

surface heating in millibars. With certain corrections, H_a may be used as equivalent to H_o and ϕ calculated. The ratio of $\frac{\text{ground absorption}}{\text{insolation}}$ then is

$$\frac{100\phi'}{I'_o} \qquad (20)$$

from which a mean of 70 per cent was calculated by Myers (1947) and the deviations from this determined for each month as already mentioned.

It is clear from this work that the state of the ground will influence night minimums (1) because of its effect on day temperatures in the biosphere, and (2) because of the different properties of the biosphere that these states influence.

The thermal conductivity (k) of wet ground is 3×10^{-3} to 8×10^{-3} cal/cm² sec °C per cm and for very dry ground 4×10^{-4} to 8×10^{-4}. Medium fine quartz sand with an 8.3 per cent moisture content has a thermal conductivity of 1.4×10^{-3}, but, as with soil, sand when dry has a much lower thermal conductivity. In the latter case $k = 6.3 \times 10^{-4}$ cal/cm² sec °C per cm (List, 1969). As a consequence, a dry soil surface will heat quickly during the day and cool quickly at night because it has a low conductivity and does not readily lose the heat being received during the day to layers of soil below it. The total reflectivity or albedo* (includes visible and infrared) of dry sand is 18 to 28 per cent, while that of wet sand is 9 per cent; dry or moist bare ground ranges from 9 to 12 per cent; wet ground, 8 to 9 per cent; dry plowed ground, 20 to 25 per cent; inland waters, 5 to 10 per cent†; old snow, 46 per cent; fresh snow, 81 per cent; ice, 69 per cent; high dry grass, 31 to 33 per cent; high wet grass, 22 per cent; and high fresh grass, 26 per cent (List, 1966). It may be expected that under clear skies, the diurnal temperature variation will be greatest over sandy soils and least over loam and clay soils.

* The albedo of the ground ("the large surface") is the ratio r/i, where i is the intensity of radiation passing to the test surface in the downward direction and r is the intensity of the upward beam from that surface (Sutton, 1953).

† Emissivity of water in an inland lake is 0.970 ± 0.005 (Straus, 1954).

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Cover Crops and Cultivation

Young (1925) showed that on a still night, air temperature five feet above a soil carrying a cover crop such as mustard was colder by 0.5° F than bare soil. On windy nights it was 11° F colder. Hilgeman, Everling, and Dunlap (1964) showed that the air above plowed ground was colder than above compacted soil. Leyden and Rohrbaugh (1963) found that citrus trees suffered great damage in the Texas freeze of 1962 where the tree interspaces were covered with weeds (tall cover) or sod, while bare-ground noncultivated plots on which chemical weed control was used suffered little damage (figs. 10–58 and 10–59).

Physiographic Factors

The degree to which the ground is warmed by the sun also depends on its slope and exposure. In citrus-growing areas in the northern hemisphere, slopes with southern exposure receive the sun's rays at a higher angle during winter and are warmer. Slopes with northern exposures are colder, but there are examples of successful citrus plantings on northern slopes in California at Corona, on western slopes at Santa Barbara, Redlands, Riverside, and the San Fernando Valley, on southern slopes at Santa Paula, (Carpenter, 1914), and on a few eastern slopes in Riverside, Corona, San Juan Capistrano, and La Quinta.

The relative heating of slopes of five different exposures and two different inclinations has been graphed by Geiger (1965) on the basis of intensity of solar radiation at 45° north latitude (figure 10–60). The quantity of solar radiation received on the slope is given in equatorial hours, which is the product of the duration of sunshine and its intensity. The unit of insolation is the amount of sunshine received by a horizontal surface at the equator in one hour when the declination of the sun is zero. Examination of the graph for the zero degree slope shows that the various slope exposures at different seasons received the same amount of radiation. The 15-degree slope which is equivalent to a 26.8 per cent slope shows great differences in the heat received by north

Fig. 10–58. Trees with large stands of weeds were badly frozen in the freeze of January, 1962, in Weslaco, Texas. Dead wood is in evidence. The size of dead trees indicates the extent of freeze damage.

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Fig. 10–59. Grapefruit trees after the freeze of January, 1962, in Weslaco, Texas, where weeds were controlled by chemical sprays. Extent of survival indicates warmer environment when weed control was used. See experiments of Leyden (1964*a*, 1964*b*) and Leyden and Rohrbaugh (1963).

and south slopes. Two recent publications present improved mathematical treatments of slope exposure and solar heating (Shadbolt, McCoy, and Little, 1961; Garnier and Ohmura, 1968).

Most of the citrus orchards in southern California have been planted on slopes not greater than 3.5 to 5 per cent, and they average considerably less than one per cent in Arizona, Texas, and Florida. As a consequence, slope-exposure though an important factor, has not been a critical one in frost protection or citrus-growing in the United States, but is of considerable importance in some Mediterranean countries and in Japan.

The relative height of parcels of ground in a limited area have important effects on nocturnal minimum temperatures and their duration during frosts and freezes (fig. 10–61). On a gentle sloping valley floor with a $\frac{1}{10}$ to 2 per cent slope, small areas a hundred feet in diameter more or less, or larger areas a mile or more in diameter which lie one to ten feet below the general larger "sink" area, on radiation nights with clear skies and calm air, will develop much lower air temperatures than the surrounding higher areas. This is the result of the downhill drainage of colder more dense air (fig. 10–62) by gravity flow into the low pocket. These pockets are known as cold-air lakes. Raised ground such as dikes, highway and railroad grades, embankments, tight hedgerows, windbreaks filled with tall weeds, and walls running at right angles to the slope will stop the downward flow of cold air on radiation nights. These are known as cold-air dams. In such cold-air lakes and updrift areas of cold-air dams, freezing air will be entrapped, while behind these pockets and on nearby hillsides the air may be many degrees warmer (plate I, *K* p. 380, and fig. 10–63). Cold-air dams with drainage openings such as streets or roads forming an opening or underpass were observed by the author to satisfactorily pass cold air. An example is the extension of El Horno Canyon under Route 101 in San Juan Capistrano, California. Frost protection methods such as cold air drainage, heating, and

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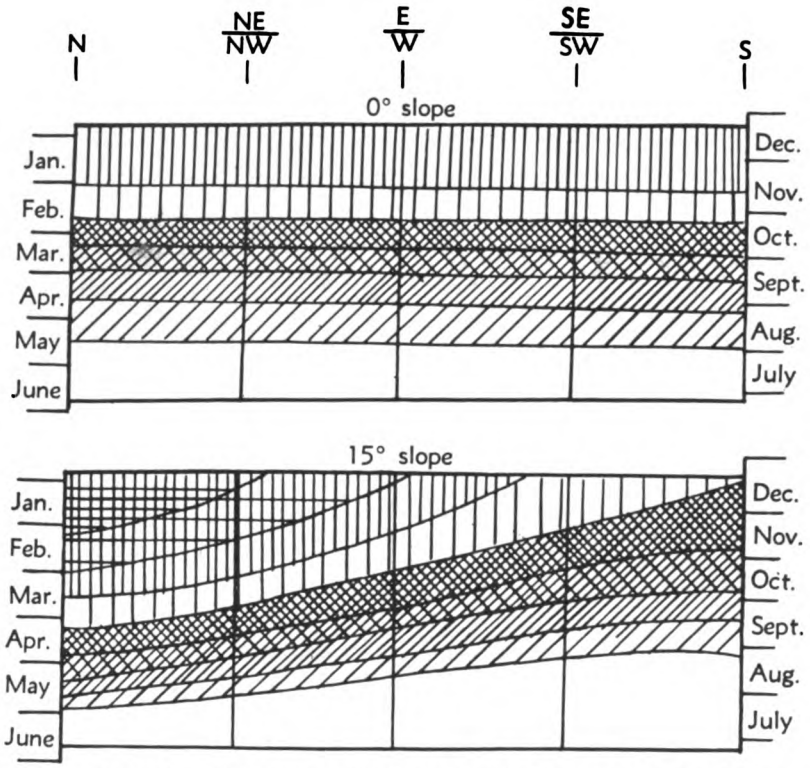
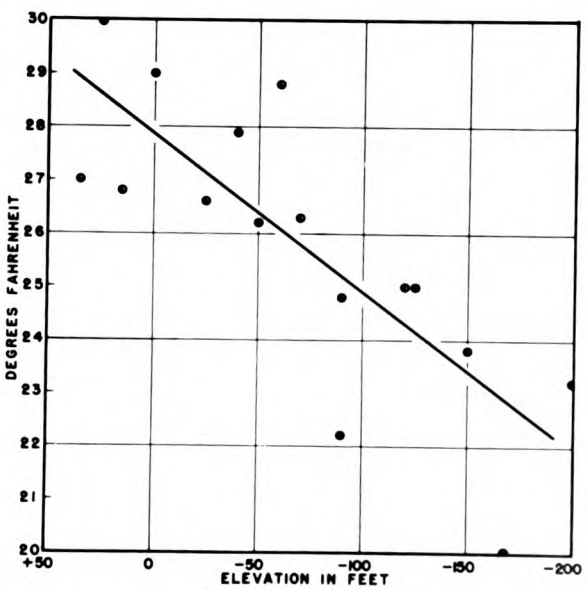


Fig. 10–60. Quantity of solar radiation graded by shading from 0 to 9 equatorial hours, on slopes of two inclinations and five exposures. Left ordinate indicates months with decreasing sun declination; right, months with increasing declination. (Geiger, 1927.)



forced convection must be applied to obtain protection in such cases.

Large areas covering hundreds of square miles may have inherent frost hazards deriving from topography also. Nearby low mountains and hills afford slopes down which colder denser night air may flow. Although this air is frequently warmed somewhat by compression (Young and Harman, 1948), such areas will be more frequently subjected to radiation frosts. For example, the Coachella Valley in Riverside County, California (altitude –200 to +50 feet sea level) has an average of six frosts each winter season, whereas the Riverside-Corona area seventy miles north-

Fig. 10–61. Low temperatures for February 3, 1956, at temperature survey stations in the Coachella Valley, California, plotted against elevation. Regression coefficient (air temperature, °F, on elevation) equals 0.0296° F per foot of elevation. (Friedman, 1959.)

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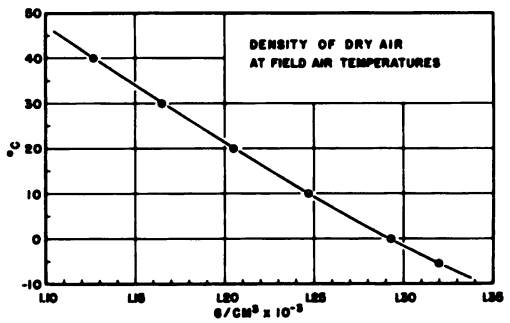

Fig. 10–62. Specific gravity (density) of dry air at 760 mm of mercury at air temperatures encountered in citrus orchards on a hot day (40° C ≡ 104° F) and on a very cold night (–9° C ≡ 15.8° F). (Lange, 1939.)

west (+400 to +875 feet sea level) has but three on the average (Cooper and Peynado, 1959).

High ground is less protected against the action of advection freezes in the early stages than in radiation frosts. Masses of cold dry air of great depth (5,000 to 10,000 feet) moving rapidly (4 to 30 mph) strike hilltops and hillsides with full velocity and cause severe desiccation and freeze damage. The hills, however, act as wind barriers and reduce the flow of air behind them, and thus give trees at lower ground levels freeze protection. The protective action of hill-barriers was readily observable in California and Florida following the freezes of 1962 and 1963, but was conspicuously absent in the 1962 freeze in the flat delta-like Rio Grande Valley of Texas. Windbreaks, dikes, embankments on the windward sides of hilltops, and other exposed elevations give frost protection during the windy stage of advection freezes. The normally warm locations are cold (hilltops) and normally cold locations (valleys) are relatively warm. On the last night of an advection freeze, the wind goes down and the cold loci reverse as a strong radiation frost sets in.

The state of the ground differs markedly in relation to physiographic and climatic features in most citrus regions. For example, in the various sections of California, the temperature of the ground surface and the air in contact with it are different in the coastal, intermediate, interior, desert, and Central Valley districts. At Anaheim (intermediate district) the soil temperature ranges 2° F to 4° F lower than at Indio (desert district) for November and December (Bliss, Moore, and Bream, 1942; and Bliss, 1944). These investigators also showed that for a period covering eight years,

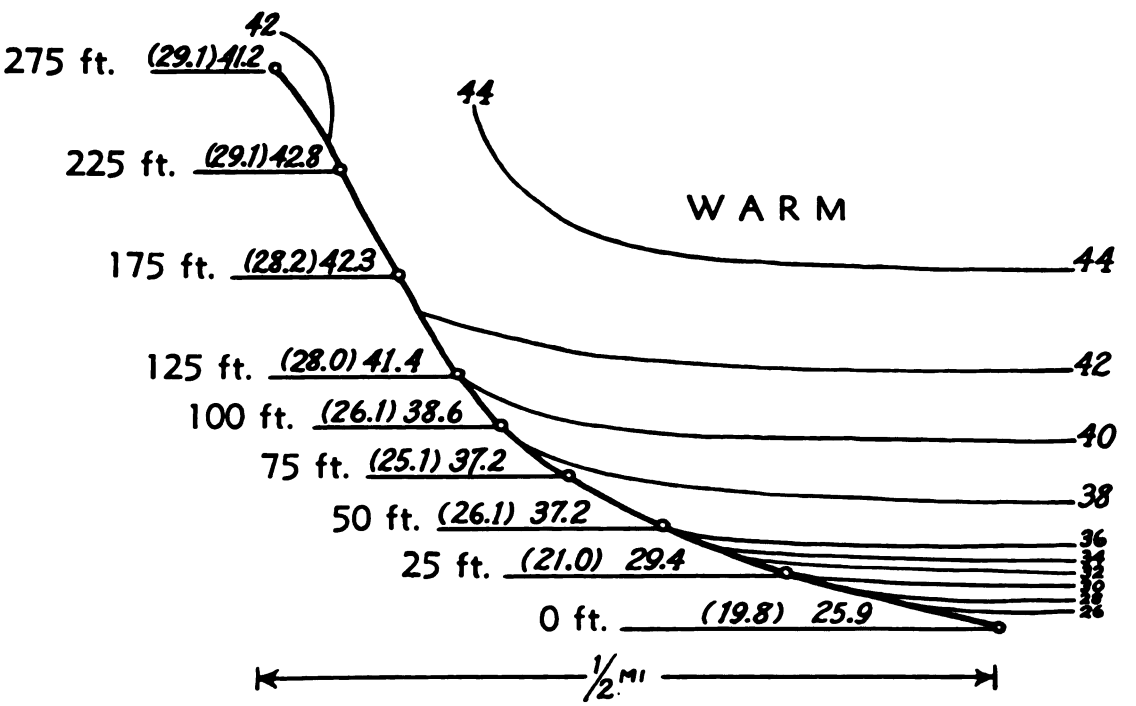

Fig. 10–63. Average minimum temperatures for 45 clear nights during the winter of 1918–19 in the Pomona Valley, California. Figures in parentheses represent a night when there was a weak temperature inversion. (Young and Harman, 1948.)

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Table 10–18
MONTHLY RANGE OF WEEKLY MEAN SOIL TEMPERATURES AT TWO DEPTHS IN UNSHADED AREAS IN CITRUS GROVES IN TWO CLIMATIC DISTRICTS IN SOUTHERN CALIFORNIA*

Years	November	December		January	February
	Temperatures One Foot Below Surface (°F)				
		Indio			
1934	61–67	52–57	1935	50–53	53–56
1935	55–64	51–59	1936	51–53	53–57
1936	60–66	54–60	1937	42–51	43–53
1937	64–70	54–62	1938	54–57	53–55
Mean	60–67	53–59		49–54	51–55
Δ	2 to 4	1 to 2		....	....
		Anaheim			
1939	59–64	54–59	1940	52–55	52–57
1940	55–63	54–56	1941	53–54	56–58
1941	57–62	48–55	1942	59–54	53–55
1942	56–61	52–57	1943	50–53	53–57
Mean	58–63	52–57		51–54	54–57
Δ	....	....		–2 to 0	–3 to 2
	Temperatures Four Feet Below Surface (°F)				
		Indio			
1934	68–70	63–64	1935	59–61	60–60
1935	63–70	60–63	1936	57–58	58–59
1936	66–70	60–65	1937	54–59	53–56
1937	69–74	64–68	1938	64–72	62–64
Mean	67–71	62–65		59–63	58–60
Δ	6 to 6	5 to 5		4 to 7	3 to 4
		Anaheim			
1939	62–66	59–62	1940	56–58	56–57
1940	60–65	57–59	1941	55–56	56–57
1941	61–64	56–59	1942	54–55	54–55
1942	60–65	56–59	1943	54–55	54–55
Mean	61–65	57–60		55–56	55–56
Δ	....	....		....	....

Source: Bliss *et al.* (1942) and Bliss (1944).
* Δ is the difference between means for a given month, at the same soil depth between different climatic districts (i.e., desert and intermediate).

at one foot below the ground surface, the temperature at Anaheim ranged from 0° F to 2° F warmer than at Indio during January and February (table 10–18). Ninety-eight per cent of the roots are contained between the 1-foot level and the 4-foot level (Bliss, 1944). Temperatures at the 4-foot depth ranged from 3° F to 7° F warmer at Indio than at Anaheim (table 10–18). From 1934 to 1943, both Anaheim and Indio had minimum mean temperatures at the 4-foot level that were 11° F warmer, and maximum mean temperatures that were 4° F warmer, than at the 1-foot level.

Soil temperatures which induce root growth seem to induce frost-damage susceptibility. Minimum temperatures for root elongation range from 48° F to 64° F, and in some cases soil temperatures of 48°F to 64° F will cause new growth on citrus to wilt even though soil moisture is adequate (North and Wallace, 1955). These temperatures of 48° F to 64° F will cause new which Girton (1927) found optimum for root growth. Cooper and Peynado (1959) have shown that the mean minimum soil temperatures at 18-inch depth at Riverside, California, is near 55° F

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for the four winter months while in Monte Alto, Texas, it ranged from 58° F for the 6-inch depth to 66° F for an 18-inch depth. Thus, the soil in the principal root zone in Texas is appreciably warmer than in southern California.

The mean monthly temperature of the ground in the principal root zone is quite different during the winter season in California, Arizona, Texas, and Florida (Cooper and Peynado, 1959; see also chap. 9). Minimum soil temperature at the six-inch depth, for example, for the nights of the December, 1961, freeze in Orlando, Florida, was 55° F, while from January 12 to 13 it was 51° F at Weslaco, Texas, and 43° F at Indio, California (Cooper, Peynado, and Furr, 1962).

The higher soil temperatures in Texas and Florida (see chap. 9) are in a range that keep citrus roots growing or on the verge of growth throughout the winter (Cooper, Young, and Turrell, 1964). These factors are partly responsible for differences in successful frost- and freeze-protection methods in the four citrus-growing states.

Lakes and Reservoirs

The presence of lakes and reservoirs near citrus orchards and the nearness to large bodies of water such as oceans and gulfs have a strong influence in ameliorating the air temperatures on advection-freeze nights. This results presumably from the very large heat capacity and thermal conductivity of water as compared with that of partially dry soil. Air in contact with the water is warmed, and it also is humidified. Then diffusion carries it slowly over the orchard, bringing it in contact with leaves and fruit. The more rapid movement of air across lakes and reservoirs during recent freezes showed that these two factors could act also so as to change the dry, freezing air to moister, warmer air which was less destructive to citrus orchards. This effect was observed in experiments using irrigation (Turrell, Austin, and Perry, 1961), during the 1962 freeze in one instance near Indio, California (Turrell, Austin, and Perry, 1965*b*), in another instance near Weslaco, Texas (Rohrbaugh, 1963), and in innumerable instances in Florida (Grierson, 1964*a*). Data for the December, 1962, freeze shows that in the lee of the lake temperatures were 1.3° F to 2° F higher at Santa Fe Lake, Florida, than to the windward (Davis, 1963). During radiation frosts, wind machines acting on lake surfaces can produce warm air for use in the citrus orchard. Based on Florida freeze records of Cooper, Peynado, and Furr (1962*a*), Grierson (1964*a*) calculated that if the windward air was 15° F and its relative humidity was 40 per cent, if after passage over the lake it was 20° F, the dry portion of the air would have gained only 1.4 BTU/lb if it had not accumulated moisture. However, it gained moisture; thus if the windward air reached a relative humidity of 100 per cent after passing over a lake, it would contain 2.8 BTU/lb. The increase in its heat content resulted from the heat absorbed by raising the relative humidity to 100 per cent at 15° F, as well as heating the dry air.

Much of the heat picked up by air in passing over a lake surface can be recovered by leeward trees in the orchard if it moves through them. It is assumed not to be effective on radiation nights without a wind machine, unless there is a hilly terrain with downslope winds crossing the lake into the orchard. Placement of a heavy wind machine on either side of a small lake should give sufficient forced convection to adequately circulate the warmed air. Orchards on the lee side of lakes receive their protection in advective freezes from the heat and moisture picked up by the wind in crossing the lake.

Evaluation of the energy advected to or from the surface of a body of water requires knowledge of its climatological, hydrological, and geographical characteristics. No method has been established which applies to all cases. However, the heat carried away from a water surface per unit area per unit time may be expressed by the equation:

$$Q_h = -C_p A \left(\frac{dT}{dz} + \gamma\right)\rho \qquad (21)$$

where C_p = specific heat of air at constant pressure, A = vertical component of the eddy conductivity, which is analogous to thermal conductivity and whose dimensions are cm²/sec, $\frac{dT}{dz}$ = the temperature gradient of the air, γ = adiabatic lapse rate, the space rate of decrease of temperature upward through the atmosphere at a particular moment when the atmosphere is in isentropic equilibrium (γ_d = 5.4° F/1000 ft or 0.98° C/100 m), and ρ is density. In the Lake Hefner studies (Wrather, 1954), however, it was not possible to evaluate the eddy conductivity with precision. This method was abandoned therefore in favor of the Bowen ratio of conducted heat (convected heat) to energy utilized by evaporation, R:

$$R = c\left(\frac{T_o - T_a}{e_o - e_a}\right)\frac{P}{1000} \qquad (22)$$

where T_o and T_a equals the temperatures of air

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and water surface (°C), and e_o and e_a equals the saturated vapor pressure at the temperature of the water surface and the water-vapor-pressure in the air (*mb*), respectively, and P equals atmospheric pressure (*mb*). The conductivity limiting values are $c = 0.58$ and 0.66. Under normal atmospheric conditions $c = 0.61$. E, evaporation per unit time, may be evaluated from:

$$E = (e_o - e_a)(a + bu) \qquad (23)$$

where a and b equal constants for 24-hour per day evaporation in inches, u equals wind movement in miles per day, e_a equals atmospheric vapor pressure in inches of mercury, and e_o equals the vapor pressure of the water surface (Wrather, 1954). Wrather (1954) reported that evaporation varied for class A pans to screened pans from 0.294 to 0.203 inches, $e_o - e_a$ from 0.324 to 0.337 inches Hg, a from 0.417 to 0.104, b from 4.0×10^{-3} to 4.4×10^{-3} and u from 122.4 to 125.8 miles/day. The remainder of the constants for equation (23) are given in table 26 of Wrather (1954).

Heat delivered to citrus orchards by small lakes like Lake Santa Fe in Florida can be roughly estimated. The first night of the 1962 freeze the temperature of this lake, about a mile in diameter, 2 inches below the surface dropped from 52° F to 47° F (Davis, 1963), and thus supplied approximately 1.14×10^9 BTU. Since a part of this energy went into evaporation, it only raised the temperature of the air from 12° F to 14° F, its heat not being sufficient to prevent the orchard on the leeward side from freezing. However, while Parson Brown trees in a similar situation on a north hilltop exposure (windward side) froze (fig. 10–64), trees on the leeward side of Lake Harris, Florida, were protected from severe damage (fig. 10–65).

On the windward side of a small reservoir at Indio, California, during the same freeze (1961–62 winter), grapefruit trees were badly damaged. On the leeside of the reservoir the trees were little damaged (pl. I, *L*, p. 380). In the latter case, it is estimated that wind machines distributed water vapor and warmed air from the reservoir equivalent to 29 return-stack heaters burning at the rate of 1 gallon of fuel per hour for ten hours. Later studies showed actually a great deal more than this amount of heat was delivered because of convection currents in the reservoir (Turrell, Perry *et al.*, 1965, Project 1731). The duration of protective action of small bodies of water, however,

Fig. 10–64. Parson Brown orange trees killed by freezing wind on hilltop near Clermont, Florida, in the freeze of December, 1962. Trees below on south side of hilltop were damaged less. Near Clermont, Florida.

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Fig. 10–65. Valencia orange trees on lee side of Lake Harris, Florida, saved from freezing north wind in the December, 1962, freeze by heat and moisture picked up from lake by the wind.

appears to be short. The well-documented temperatures obtained by Davis (1963) for Lake Santa Fe and environs indicate a heat yield for a single night only.

THE PHYSIOLOGY OF FREEZE DAMAGE

Little appears to be known of the actual mechanism of frost damage. Not only do the different plant parts have different undercooling points and different freezing points (table 10–19), but these are on a sliding scale. Maximum susceptibility to frost damage coincides with maximum growth rate, and minimum frost damage occurs when the plant is most dormant or has sustained the greatest hardening. The growth response of different varieties to specific temperatures seems to account for their susceptibility or resistance to frost or freeze damage.

As citrus organs are cooled below the freezing point of water, water appears in the intercellular spaces of the tissues. Leaves, fruit-peel (Turrell and Weber, 1955), and, on rare occasions, the bark of smaller twigs (Peynado, Young, and Cooper, 1963*b*) are similarly affected and this gives the external tissues a water-soaked appearance. Leaves near the ground have this appearance before sunrise, but the water is resorbed into the cells, and the leaves appear normal after sunrise. Water invades the intercellular space prior to the freezing of the tissue, and thus the liberation of heat is that from ice formation in the intercellular spaces during the process of freezing, and is of common occurrence in most plant tissues (Levitt, 1957). Freezing of intracellular water, while it undoubtedly occurs, has not been seen in citrus. The induction of flow of water from the supercooled cells to the intercellular space prior to freezing appears to be similar to the effect of heavy metal poisons (Örskov, 1934) and sulfur (Turrell, Chervenak, and Vanselow, 1952) in causing the flow of water from cells into the intercellular spaces.

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Table 10–19
MINIMUM FREEZING POINTS FOR CITRUS TISSUE, DURATION, AND MINIMUM AIR TEMPERATURES FOR MID-NOVEMBER, 1958

Variety	Locus	Lowest Freezing Points (°F)*			Hours Below 32° F	Minimum Temperature (°F)
		Pulp	*Peel*	*Leaves*	*Air*	*Air*
Grapefruit	Indio	27.9	26.6	.....	11	21
Lemons	Ventura	28.1†	26.9†	25.0†	10	25
Valencia oranges	Elsinore	26.4	25.6	27.9	11	19 & 21
Washington navel oranges	Elsinore	28.1	27.9	.....	11	20 & 21

Source: Whiteman (1957) and Turrell and Austin (1958, 1960*b*).
* Detached leaves and fruit.
† Attached leaves and fruit.

Two or three events are necessary to make this flow possible: (1) the water must be released from the vacuoles, (2) the water must be released by the waterbinding forces in proteins and other constituents, and (3) the cell membrane must become permeable to water. In view of the similarity of the effects of sulfur, heat, and heavy metals to those of freezing, it seems likely the membrane must break at the GSSG bridges.

The cell membrane is considered to be a lipoid film two molecules thick, with its polar groups in an oil-water interface and the non-polar CH_2– and CH– groups facing inwards toward the cell. A protein net is adsorbed to the liquid hydrocarbon film, the cross-linked meshwork of polypeptide chains giving the lipoid a structural stability and the membrane its sieve-like properties (Davson and Danielli, 1943). Thus a break in the GSSG cross linkages due to cold-induced contraction resulting from the crystallization of water coordinating with –SH and –OH groups of the tightly-stretched net seems not unlikely. Such events would permit the flow of water from the cells to the intercellular spaces. It seems probable that, since water reaches its greatest density at 3° C to 4° C (List, 1966) and then expands as the temperature decreases, rupture of the cross links may take place under the pressure of the expanded and more viscous water at 0° C or in supercooled water from this temperature on down to –13° C. From the former to the latter temperature, the density decreases 3.07×10^{-3} gm/cm^{-3}, the viscosity increases 1.4 times, and the expansion per unit volume increases 3.31×10^{-3} times. However, the breaking of these linkages does not seem to result in injury. The cross links usually rejoin under warm temperature conditions provided the temperature change is not too rapid (Mirsky and Pauling, 1936). These changes may also effect the lipoid film separation that permits water leakage without the occurrence of freezing. The longer the minimum temperature duration, the greater become the statistical chances of crystallization. Sooner or later, the freezing process is triggered and the supercooled water in the intercellular space becomes ice. Salt (1961), working with insects, stated the probability of nucleation, expressed as a rate of freezing, r, and as a function of the length of exposure time, t, in an equation resembling that of the compound interest law:

$$y_t = y_o e^{-rt} \qquad (24)$$

where y_t is the number of specimens *unfrozen* at time, t, out of an original population, y_o, and where e is the base of natural logarithms, and for a single temperature. Increasingly lower temperatures increase "the probability of nucleation and eventually make it virtually certain." The probability equation is applicable to freezing of fruit, leaves, or stems of citrus trees.

The holes in the cell membrane, required to allow water to flow outward, might be caused by temperature fluctuations above and below freezing in a fashion similar to that used by Claude and Rothen (1940) in which they separated lipoid and nucleoprotein by repeatedly freezing, thawing, and extracting. The release of phospholipids is concomitant with denaturation of associated proteins and possible with their loss of hydrophilic properties that regulate the transfer and exchange of water through membranes (Claude, 1949).

The Modlibowska and Rogers moving-picture film of the freezing of plant tissue (1955)

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shows the rapid-fire order in which freezing of cells occurs. Within a cell it is an instantaneous action, and may be nearly so in an organ (Turrell, Austin, and Perry, 1960*b*).

Freeze damage of one kind may be pictured as taking place in the following manner. Water has reached the intercellular space, say at 0° C, and undergoes supercooling with attendant small decreases in density as the temperature is lowered degree by degree to –13° C (fig. 10–66). The decrease is small, averaging 2.26×10^{-4} gm cm^{-3} per degree, for a total of 2.94×10^{-3} gm cm^{-3} (List, 1966). Since density is an inverse linear function of cubic expansion, the cubic expansion of supercooled water is small. On nucleation the supercooled water will be converted suddenly to ice, which has a density of 9.16×10^{-1} gm cm^{-3}

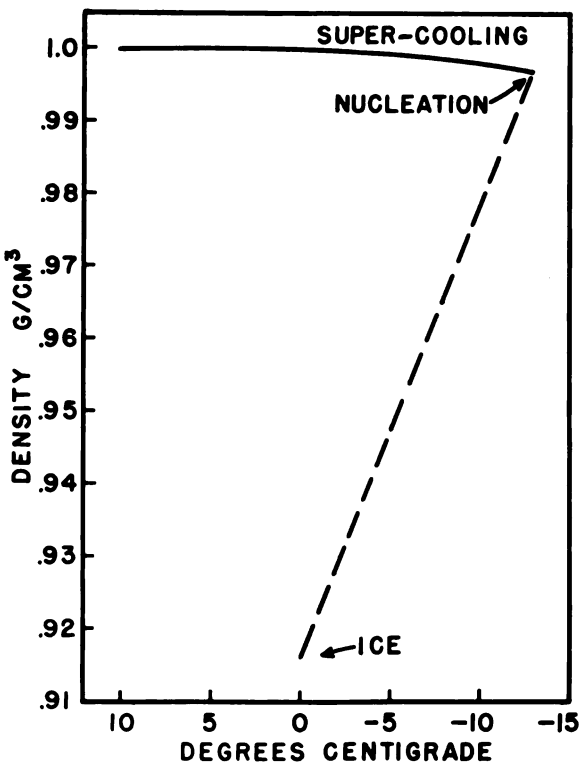

Fig. 10–66. The density of water decreases slightly in cooling from 10° C to –13° C (supercooling, upper curve), but on nucleation the supercooled water expands about three diameters when it crystallizes into ice, and its density shows a large decrease. The small expansion of super-cooled water may account for the lack of frost damage when ice formation does not occur. However, on the other hand, the large expansion of supercooled water in forming ice probably disrupts the internal juxtaposition of parts in the cell and causes freeze damage.

(List, 1966). The difference between the density of supercooled water at this temperature and ice is 8.38×10^{-2} gm cm^{-3}. Using the density as an expression of cubic dimensional change, water, in changing to ice, undergoes a cubic expansion of over 27 times, and a linear expansion of $\sqrt[3]{27}$ or three diameters. In tissues having large intercellular spaces no damage would be expected, and, in fact, damage in citrus is not common. However, if freezing occurs inside the cytoplasm of the cell (intracellular freezing) when the cell membrane is shrunken around the shrunken cytoplasm and a volume of supercooled water, there is little doubt that an increase of 27 volumes in water content would be equivalent to an explosion. Wreckage of the internal cytoplasmic structure and the cell membrane would be certain. This process of freezing and thawing has long been used to disrupt plant and animal tissues preparative to sap analyses.

Two equations have been developed by Mazur (1965) which establish the thermodynamic equilibrium when the environment is frozen around a cell and when it is supercooled internally to about –10° C. Since, under these conditions, a higher vapor pressure is established internally than externally, either supercooled water must flow out of the cell or ice must be formed intracellularly in order to maintain equilibrium. There is no freeze damage in the former case, but intracellular ice formation in the latter case is fatal. Mazur (1965) has developed two equations which predict the conditions necessary for the former:

$$\log \frac{P_i}{P_e} = \frac{L_f}{R}\left(\frac{\Delta T}{T T_f}\right) + \log\left(\frac{x_1}{x_1^f}\right) \qquad (25)$$

and

$$-\frac{dV}{dt} = \frac{k\,ART}{v_1} \log \frac{p_i}{p_e}, \qquad (26)$$

where p_i equals intracellular vapor pressure, and p_e equals extracellular vapor pressure, L_f equals molar heat of fusion and R equals gas constant, T_f equals normal freezing point of the cell contents, x_1 equals mole fraction in the cell at temperature T and x_1^f equals mole fraction at temperature T_f, V equals volume of intracellular supercooled water, t equals time (cooling velocity) in minutes, k equals permeability constant of the cell for water, A equals area of the cell surface, and v_1 equals molar volume of water. When the

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relation between T and t is known, and B equals uniform cooling velocity, b equals temperature coefficient (0.065) of permeability constant, and k_g equals permeability constant at temperature T_g, these two equations (25 and 26) may be combined to obtain V thusly:

$$T_e^b(T_g - T)\frac{d^2V}{dT^2} - \left[(bT + 1)e^{b(T_g - T)} - \frac{ARk_g n}{B(V + nv_1)} \cdot \frac{T^2}{V}\right]\frac{dV}{dT} = \frac{L_f A k_g}{Bv_1}. \quad (27)$$

The solution of this equation, when compared with $\frac{V}{V_i}$ for yeast at a cooling velocity of 1° C/min, shows them to be quite close, from temperatures of 0° C to –18° C. Cooling rates in orange groves in southern California are much slower (1 to 2° C/hr or 1.8 to 3.6° F/hr). As a consequence, the supercooled water from citrus tissues flows from the cell interiors to the intercellular spaces, the intracellular vapor pressure remaining very close to the equilibrium vapor pressure. This represents a desiccation of the protoplasm of the cell and particularly of the membranes surrounding the protoplasmic surface. If the extruded cell sap is then removed from the intercellular spaces of the organ by a dry wind, such as accompanied the 1913 California freeze and subsequent advection freezes, a large amount of damage results. American observers have noted "that 50% of the freeze damage was a result of desiccation" (Carpenter, 1914). Russian observers (Vasil'yev, 1961) believe that "winter-killing" is largely a result of desiccation, which, in turn, very likely is a result of such concentration of salt that damage to the protoplasm occurs. However, no solutions to Mazur's equations have been made for cells of citrus organs, since, as he asserts, the cooling velocities of different cells "vary at least over a 5,000-fold range" in order to produce intracellular ice. No realistic views can be developed until this is done. Although rates of cooling the grove do not approach those of 60° C/hr, which yeast attains in the laboratory, the slow rates of cooling under the severest field conditions may induce intracellular freezing. This is indicated by the effect of maturity (i.e., the lowering of the freezing point in Washington navel orange juice by its high sugar concentration as compared with that in the Valencia orange).

Citrus trees that are actively growing long have been known to be more susceptible to frost damage than inactive or dormant plants (Cooper, Young, and Turrell, 1964). Citrus trees in southern California and Arizona become dormant in the early part of the winter and become "hardened" as the winter progresses. Citrus trees in Texas and Florida, depending on the variety, may grow continuously throughout the winter or suffer one to many periods of interrupted growth for various lengths of time. Why leaves and stems, which are the vegetative organs of the plant, when in active growth are so susceptible to frost is not known. However, sufficient information is now at hand that target areas for future research might be designated.

Cells in the growth process usually are fully hydrated. This is shown in table 10–20 for unhardened leaves which contain 75.5 per cent of water (Young and Peynado, 1965). Iljin (1953) has shown that during growth vacuoles increase in size and the cells decrease in tolerance to dehydration, and that large fully-hydrated cells have large vacuoles. It may be conjectured that the plasma membrane is tightly stretched, that the cytoplasmic and nuclear proteins are fully unfolded, and that the full complement of water molecules are buoying up the protein frameworks at each hydroxyl, sulfhydryl, and similar groups. The cells shrink or swell as a consequence of decrease or increase in the size of the vacuole. When the vacuole is large, the disturbance within the protoplast is large. Osmotic pressure does not seem to be important *per se*, but the magnitude of its change is very important. The magnitude of change is larger, relatively, in the larger cells in tissues undergoing growth expansion. In large cells of 75,000 μ^3 volume, a change of 1.6 to 1.8 times results in death, and in small cells of less than 10,000 μ^3, when a change of four to five times occurs, death results. Intermediate-sized cells perish when volume changes of 2.3 to 3.5 times occur. Large cells, with large vacuoles, may lose sufficient water through desiccation to cause a shrinkage of five times their volume, while small cells, often resistant to death by desiccation, will suffer volume changes of only 1.8 to 2.0 times. Cylindrical cells are more tolerant to drying than isodiametric, cubical, or spherical cells. The cell surface-volume ratio is a most important factor in the survival of desiccation. The smaller the surface area and the greater the volume, the less tolerant is the protoplast. While severe desicca-

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Table 10–20
CHANGES IN COLD HARDINESS AND RELATED FACTORS OF RED BLUSH GRAPEFRUIT LEAVES AND STEMS AS AFFECTED BY VARIOUS LENGTHS OF EXPOSURE TO DAY TEMPERATURES OF 60° F AND NIGHT TEMPERATURES OF 40° F

Number of Days at 60° F and Nights at 40° F	Leaves			Stems	
	Water (%)	Cell Sap Conductivity (Mmhos/Cm³)	L.T. 50* (°F)	Bark Slip†	L.T. 50* (°F)
0	75.5	5.2	25.0	2.5	22.5
14	74.3	4.9	23.5	1.6	22.0
28	72.7	4.9	23.0	1.4	21.0
42	72.1	....	23.0	1.5	20.0
L.S.D.‡ 0.05	2.8	N.S.‡	.....	0.4	.....
0.01	3.9	N.S.‡	.....	0.5	.....

Source: Young and Peynado (1965).
* L.T. 50 are the lethal air temperatures that caused 50 per cent killing of leaves or stems under test conditions.
† The bark peeling test developed by Cooper, Taylor, and Maxwell (1955) has been shown to be a semi-quantitative measure of the degree of dormancy of citrus trees: 0 = bark does not peel; 1 = bark barely peels; 2 = bark peels easily; 3 = bark peels easily and is moist. Bark slipping was tested approximately 4 to 6 inches from the terminal of the stem.
‡ L.S.D. is the least significant difference: 0.01 = 1 per cent level, 0.05 = 5 per cent level. Nonsignificance of differences between means is indicated by N.S.

tion or hydration, on single occasions, may be lethal, as found in the case of Ezo spruce by Sakai (1968), they were not so hazardous as repeated plasmolyses and deplasmolyses (Iljin, 1953). These repetitious events, Iljin believed, caused a change in the structure of the protoplasm. The most likely cause of the denaturation is the sticking of parts of the protein framework when there is not sufficient water to float it. Breakage on rehydration may be a secondary mode of injury.

Susceptibility to frost death (desiccation) in the expansion phase of growth is not the only point of weakness. This also holds for the cell multiplication or cell division phase. Ivanov (1939) found a high negative correlation between soluble (reduced) glutathione and frost hardiness of citrus leaves and twigs of various varieties of citrus (table 10–21), and there was a positive correlation between the killing of twigs and leaves and lack of hardening and between lack of hardening and glutathione content of the organs (table 10–22). Glutathione is known as the activator of cell division. Thus cells are prone to damage when the protein framework is stretched in various ways over a relatively large fluid area in cytokinesis, and resistant to coagulation (frost damage) when the nucleus is in the normal state in which protein forms a floating network rather than being resolved into the various shapes characteristic of karyokinesis.

Table 10–21
THE RELATION BETWEEN FROST DAMAGE AT –8° C AND THE REDUCED GLUTATHIONE CONTENT OF CERTAIN ORGANS IN VARIOUS SPECIES OF CITRUS PLANTS

Plant	Frost Injury		Reduced Glutathione Content			
	Twigs	Leaves	Liber*		Leaves	
	(Per Cent)	(Per Cent)	(Mg/Gm)	Per Cent	Mg/Gm)	(Per Cent)
Mandarin Unshiu	0	18	0.1574	100	0.6537	100
Orange	8	55	0.1775	113	0.8796	134
Lemon	60	100	0.2179	139	1.1510	176

Source: Ivanov (1939).
* Bast, phloem, and inner bark.

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Table 10–22
THE EFFECT OF HARDENING LEMON PLANTS ON FROST DAMAGE AT –6° C AND THE REDUCED GULTATHIONE CONTENT OF CERTAIN ORGANS

Conditions of Hardening	Injury to Twigs (Per Cent)	Injury to Leaves (Per Cent)	Glutathione in Leaves (Mg/Gm)
Not hardened	86	100	1.235
At –6° C for 8 nights	32	98	1.198
At +2° C for 8 nights	6	70	0.840

Source: Ivanov (1939).

ACKNOWLEDGMENTS

The author is deeply indebted to his colleague, Dr. S. W. Austin, and is most appreciative of his efforts, far beyond the call of duty over these past twelve years in assisting in the carrying out of the punishing heat transfer tests in citrus groves on freezing nights. I also acknowledge with thanks the use of many heretofore unpublished graphs drawn by Dr. Austin.

The author is grateful for the generous aid and cooperation of Professor Russell L. Perry of the Department of Agricultural Engineering, University of California, Los Angeles and Riverside, who participated in research basic to this chapter and to whom the author is greatly indebted for a critical reading of this work and for two unpublished graphs. The writer wishes to thank Phyllis Nash, Statistician, Department of Soil Science and Agricultural Engineering, University of California, Riverside, for checking the mathematical developments presented herein. The Baird-Atomic Corporation of Boston, Massachusetts, generously provided the loan of an Evaporograph for making the infrared pictures shown herein, and Arthur DiMattia rendered able assistance in helping us master the techniques involved. It is also a pleasure to recall the many occasions when Mr. R. Roy Simpson, Ray Randall, and especially Dale R. Harris of the U. S. Weather Bureau's Fruit Frost Service furnished much needed aid in the form of advance freeze forecasts, which made the basic work for this chapter possible.

The breadth of coverage of this chapter would not have been possible without the generous assistance of Dr. R. H. Young of the Department of Agriculture's Research Service, and Dr. P. W. Rohrbaugh, Director of the Texas College of Arts and Industries, Weslaco, Texas, in locating the various areas of frost damage in the Rio Grande Valley, supplying information about the 1962 freeze, and providing laboratory facilities for certain special studies which otherwise could not have been accomplished. The advice and hospitality of Dr. Robert Hilgeman, Director of the University of Arizona Citrus Farm, in making the Arizona citrus area and its frost problems available, is greatly appreciated. Most gratefully acknowledged is the great and ever present help of Dr. William C. Cooper, Leader, U.S.D.A. Agricultural Research Service, Citrus Research Investigations, who made it possible for the author to examine the 1962 frost-damaged areas of Florida at first hand and to understand the environment of the freeze and of freeze recovery in 1963.

More than fifty citrus growers and citrus-growing companies in southern California cooperated in placing their facilities, personnel, and records at our disposal. The success of much of the work has been a result of generous aid furnished by Mr. Harold Ormsby and Stanley Wear, Ventura Coastal Lemon Company, Ventura; the Homer Jamison Ranch, Indio; Charles Pease of the Tee Pee Ranch, of Elsinore; the Alexander Kindig Ranch at Indio; Mr. Paul Ames of Indio; the Sunny Dune Ranch at Indio; and the Manuel Mapula Ranch at Indio.

Grateful recognition is due Joseph L. Hearn, Chihuahua, Mexico, for his most able and gracious help in making it possible for us to survey the 1962 citrus freeze damage in Mexico, the recovery in 1963, and for introducing us to meteorologists familiar with the meteorology of Mexico.

The author is most appreciative of the help given by Margaret Gross and Karen Flanders Blackwell in typing the manuscript and Donnice

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Ross and Mary Bell Johnson in providing much of the necessary technical assistance in assembling and checking the manuscript. And lastly, the author expresses his thanks to Dr. Walter Reuther and to Mr. Harry Lawton for their editing of a long and difficult manuscript.

LITERATURE CITED

ADAMS, R. L. 1952. Protecting citrus groves from frost. Costs and benefits to growers. Calif. Agr. Expt. Sta. Bul. 730: 61 pp.

ADEL, A. 1958. A comparison of the net radiation losses by the earth's surface in the spectral region 5mμ – 14 mμ and 14 mμ – 24 mμ. Scientific Rept. HB-3, Contract AF19(604)-2177. Air Force Cambridge Res. Center, Bedford, Mass.

ALBRECHT, J. 1967. Fighting frost effectively. Citrus Veg. Mag. 31(4):14, 22.

ALDRICH, J. H., and M. MEADOWS. 1962. Southland weather handbook. Brewster Publications, Los Angeles, Calif. 51 pp.

ANGUS, D. E. 1962. Frost protection experiments using wind machines. Div. Meteor. Phys. Tech. Pap. 12: 44 pp. Commonwealth Sci. Indus. Res. Org., Australia.

ANONYMOUS. 1919. Breeze-creating machine to protect from frost and heat. Calif. Citrog. 4:268.

——— 1922a. Covina's frostless convention and Pan-city exposition. Los Angeles Examiner, May 1, Section 1, p. 6.

——— 1922*b*. $30,000 pledged for frost control study. Los Angeles Examiner, March 18, Section 2, p. 4.

——— 1922*c*. Wind device favored to rout frost. Los Angeles Examiner, March 17, p. 1.

——— 1924. Tests made on Whittier ranch of temperature regulator. Calif. Citrog. 9:174, 202.

——— 1937. Orchard heaters and past winter's freeze discussed at series of meetings. Calif. Citrog. 23: 86–87.

——— 1939. Grower uses infra-red ray lamps for frost protection. Calif. Citrog. 24:159, 179.

——— 1946. Infra-red ray frost fighter. Amer. Fruit Grow. 67(6):23.

——— 1952. Use of wind machines in Orange County. Calif. Citrog. 37:137.

——— 1954. Wind machine propellers. U. S. Propellers, Inc. Pasadena, Calif. 21 pp.

——— 1956. Firing information. Calif. Citrog. 42:22.

——— 1960. Hetero-auxin frost-preventative spray. Ministry of Agr., Armenian SSR. Embassy of the Soviet Union, Report to Dr. Walter Carleton, Washington, D.C. Translated by Margaret Miller FAS, FAAD.

——— 1962*a*. Valley saves 39% of grapefruit and 55% of oranges. Calif. Citrog. 47:187.

——— 1962*b*. Comtel Reuter Reports from London.

——— 1963*a*. Fall treatments (1963) for citrus groves including cold damaged trees. Citrus Indus. 44(10):3.

——— 1963*b*. USDA reports on Mediterranean citrus cold damage. Citrus Indus. 44(3):29–30.

——— 1963*c*. Numbers of wind machines. Citrus Veg. Mag. 26(10):3.

——— 1963*d*. Record blast of arctic weather whips the world—Hell's winter howls in. Life 54(6):28–39.

——— 1963*e*. That Florida freeze. So. Calif. Rancher, May–June, p. 9.

——— 1964. Frost protection guides. Calif. Citrog. 50: 28–31.

——— 1966. A hailstorm probe. NCAR Quart. 1(14):1–4.

——— 1967. Here's the latest in frost control. Amer. Fruit Grow. 87(3):11–14, 16, 50–51.

——— 1968. Studies indicate foam has possibilities in crop frost protection. Packer 74(51):1.

——— 1969. Rules and regulations. Riverside Co. Air Pollution Control Dist., Riverside, Calif. 35 pp.

——— 1970. Protective fog for crop and gardens. Information Sheet 1. Mee Industries, Inc., Mendocino, Altadena, California.

——— 1971*a*. Frost protection temperature data. Citrograph 57:18, 23.

——— 1971*b*. Helicopters: the moveable wind machines. Citrograph 57:8, 23–24.

——— 1971*c*. Turn on the heat with the fire wagon. Amer. Fruit Grow. 91(3): 26, 28.

BARKER, J. B. 1964. Frost control with natural gas and wind machines. Amer. Fruit Grow. 84(4):10–12, 49–50.

BARNES, K., and K. R. FROST. 1966. Solid fuel heaters for citrus groves. Prog. Agr. Ariz. 18(6):21–23.

——— 1969. Petroleum coke heaters: Labor requirements and temperature effects in under tree and between-tree placement. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. II:525–28. Univ. Calif., Riverside, Calif.

BARNETTE, R. M., E. F. DEBUSK, J. B. HESTER, and H. W. JONES. 1931. The mineral analysis of a nineteen-year-old Marsh seedless grapefruit tree. Citrus Indus. 12(3):5–6, 34.

BARTHOLOMEW, E. T., W. B. SINCLAIR, and R. P. HORSPOOL. 1950. Freeze injury and subsequent seasonal changes in Valencia oranges and grapefruit. Calif. Agr. Expt. Sta. Bul. 719: 47 pp.

BATCHELOR, L. D., and H. J. WEBBER (eds.). 1948. The citrus industry. Vol. II. Production of the crop. Univ. Calif. Press, Berkeley and Los Angeles. 933 pp.

BATTAN, L. J. 1963. A survey of recent cloud physics research in the Soviet Union. Bul. Amer. Meteor. Soc. 44:755–71.

BAUMEISTER, T., and L. S. MARKS. 1964. Marks' mechanical engineers' handbook. McGraw-Hill Book Co., New York. 2,270 pp. [Sixth edition.]

BEESE, N. C. 1942. Infra-red radiation. Science 95:614–17.

BERRY, F. A. JR., E. BOLLAY, and N. R. BEERS. 1945. Handbook of meterology. McGraw-Hill Book Co., Inc., New York, 1,068 pp.

BINDER, R. C. 1949. Fluid mechanics. Prentice Hall, Inc. New York, 361 pp.

BLAIR, T. A. 1909. Northers of the Sacramento valley. U. S. Dept. Agr. Mon. Weather Rev. 37:132–33.

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BLANCHARD, V. F. 1934. Depressing effects of wind on growth and yield of citrus trees. Calif. Citrog. 19:206.

——— 1937. Rebuilding frost-injured citrus trees. Calif. Citrog. 22:184, 216–18.

BLISS, D. E. 1944. Air and soil temperatures in a California citrus orchard. Soil Sci. 58:259–74.

BLISS, D. E., D. C. MOORE, and C. E. BREAM. 1942. Air and soil temperatures in a California date garden. Soil Sci. 53:55–64.

BIALOGLOWSKI, J. 1936. Effect of humidity on transpiration of rooted lemon cuttings under controlled conditions. Proc. Amer. Soc. Hort. Sci. 33:166–69.

BOELTER, L. M. K., H. S. GORDON, and J. R. GRIFFIN. 1946. Free evaporation into air of water from a free, horizontal, quiet surface. Indus. Eng. Chem. 38:596–600.

BOELTER, L. M. K., V. H. CHERRY, H. A. JOHNSON, and R. C. MARTINELLI. 1946. Heat transfer notes. Univ. Calif. Press, Berkeley and Los Angeles. 622 pp.

BÖHNING, R. H., and B. LUSANANDANA. 1952. A comparative study of gradual and abrupt changes in root temperature on water absorption. Plant. Physiol. 27:475–88.

BOSEN, J. F. 1958. An approximation formula to compute relative humidity from dry bulb and dew point temperatures. U. S. Dept. Agr. Mon. Weather Rev. 86:486.

BROOKS, F. A. 1957. An introduction to physical microclimatology. Univ. Calif., Davis. 264 pp. [*See specifically:* p. 154.]

BROOKS, F. A., C. F. KELLEY, D. G. RHOADES, and H. B. SCHULTZ. 1951. Heat transfer in citrus groves. Frost protection studies of effectiveness of wind machines alone and in combination with heaters. Calif. Agr. 5(8):5, 14–15.

BROOKS, F. A., A. S. LEONARD, T. V. CRAWFORD, and H. B. SCHULTZ. 1961. Frost protection by wind machines and heaters. Amer. Soc. Agr. Eng. 4:192–98, 202.

BROOKS, F. A., D. G. RHOADES, and A. S. LEONARD. 1952. Wind machines: 90 and 15 bhp machines compared for frost protection at Riverside. Calif. Agr. 6(8):7–8.

BRUNT, DAVID. 1939. Physical and dynamical meterology. Cambridge Univ. Press, Cambridge. 428 pp.

BURNS, R. M., M. J. GARBER, and H. Z. HIELD. 1962. MH sprays and frost protection of young trees. Calif. Citrog. 47:384, 392, 394–95.

BURNS, R. M., K. W. HENCH, and H. Z. HIELD. 1964. MH growth inhibition effects on young navel trees. Calif. Citrog. 49:396–400.

BUSHMAN, E. E. 1965. Citrus tree winter insulation experiments. Report on 1963–4 and 1964–5 tests. Laguna Beach, Calif. 4 pp. [Mimeo.]

CAHOON, G. A., E. S. MORTON, B. W. LEE, and G. E. GOODALL. 1963. The use of plastic ground covers in citrus nurseries. Proc. Amer. Soc. Hort. Sci. 83: 309–15.

CAHOON, G. A., B. L. GROVER, and I. L. EAKS. 1964. Rind oil spotting of lemons, cause and control. Calif. Citrog. 49:411, 422, 424, 426, 428.

CAMERON, S. H., and D. APPLEMAN. 1934. The distribution of total nitrogen in the orange tree. Proc. Amer. Soc. Hort. Sci. 30:341–48.

CANADA, A. H. 1948. Simplified calculation of black-body radiation. Gen. Elect. Rev. 51(12):50–54.

CARPENTER, F. A. 1914. Utilization of frost warnings in the citrus region near Los Angeles, Calif. U. S. Dept. Agr. Mon. Weather Rev. 42:569–71.

——— 1919. Southern California windstorm of Nov. 24–26, 1918. U. S. Dept. Agr. Mon. Weather Rev. 47: 26–27.

CARSLAW, H. S. 1945. The flow of heat in a sphere and cone. *In:* Introduction to the mathematical theory of the conduction of heat in solids. Chap. 8, pp. 135–48. Dover Pub., New York.

CARSLAW, H. S., and J. C. JAEGER. 1959. The heating of a chain of radiating slabs. Laminated materials. *In:* Conduction of heat in solids. pp. 415–16. Second edition. Clarendon Press, Oxford.

CHESNESS, J. L., H. J. BRAUD, and P. L. HAWTHORNE. 1968. Freeze protecting strawberries with foam insulation. Abstr. 65th Ann. Meet. Amer. Soc. Hort. Sci. Univ. Calif., Davis, Calif. 119 pp. [*See specifically:* p. 103, Abstr. 109A.]

CLAUDE, A. 1949. Proteins, lipids and nucleic acids in cell structure and functions. *In:* Anson, M. L. and J. T. Edsall. (eds.). Advances in protein chemistry. Academic Press, Inc., New York. 481 pp.

CLAUDE, A., and A. ROTHEN. 1940. Properties of the causative agent of chicken tumor. XIV. Relation between a tumor nucleoprotein and the active principle. Jour. Exptl. Med. 71:619–33.

COIT, J. ELLIOT. 1915. Citrus fruits. The Macmillan Co., New York. 520 pp.

COOPER, W. C. 1959. Cold hardiness in citrus as related to dormancy. Proc. Fla. State Hort. Soc. 72:61–66.

——— 1963*a*. Comparison of freeze damage to citrus in Florida, Texas, Arizona, and California. Citrus Veg. Mag. 26(8):20, 22, 27.

——— 1963*b*. The rehabilitation of freeze-damaged citrus trees. Citrus Veg. Mag. 26(6):12–14, 16, 18.

——— 1965. Concepts of tree dormancy, cold hardiness, and freeze injury in relation to citrus. Proc. Rio Grande Val. Hort. Soc. 19:40–47.

——— 1968. Healing of split bark in Texas. Personal communication.

——— 1969. Ethylene production in freeze-injured citrus trees. Proc. Rio Grande Val. Hort. Soc. 23: 29–37.

COOPER, W. C., C. J. HEARN, G. K. RASMUSSEN, and R. H. YOUNG. 1963. The Florida freeze. Calif. Citrog. 48(6):217–20.

COOPER, W. C., and A. PEYNADO. 1955. Effects of plant regulators on dormancy, cold hardiness, and leaf form of grapefruit trees. Proc. Amer. Soc. Hort. Sci. 66:100–10.

——— 1958. Effect of gibberellic acid on growth and dormancy in citrus. Proc. Amer. Soc. Hort. Sci. 72:284–89.

——— 1959. Winter temperatures of 3 citrus areas as related to dormancy and freeze injury of citrus trees. Proc. Amer. Soc. Hort. Sci. 74:333–47.

COOPER, W. C., A. PEYNADO, and J. R. FURR. 1962. Effects of 1961–62 winter freezes on Valencia oranges in Florida, Texas and California. Proc. Fla. State Hort. Soc. 75:82–88.

COOPER, W. C., G. K. RASMUSSEN, A. PEYNADO, R. H. HILGEMAN, G. A. CAHOON, and K. OPITZ. 1963. Freeze injury and recovery of citrus trees as affected by climate before and at time of freeze. Proc. Fla. State Hort. Soc. 76:97–104.

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COOPER, W. C., G. K. RASMUSSEN, and E. S. WALDON. 1969. Ethylene production in freeze-injured citrus trees. Proc. Rio Grande Val. Hort. Soc. **23**:29–37.

COOPER, W. C., P. C. REECE, and J. R. FURR. 1962. Citrus breeding in Florida, past, present, and future. Proc. Fla. State Hort. Soc. **75**:5–13.

COOPER, W. C., S. TAYLOR, and N. MAXWELL. 1955. Preliminary studies on cold hardiness in citrus as related to cambial activity and bud growth. Jour. Rio Grande Val. Hort. Soc. **9**:1–15.

COOPER, W. C., R. H. YOUNG, and F. M. TURRELL. 1964. Microclimate and physiology of citrus: Their relation to cold protection. Agr. Sci. Rev. **2**(1):38–50.

COULTER, T. H. 1962. *N*-vinyl-2-pyrrolidone polymer for frost protection of plants. U. S. Patent Office. Pat. No. 3,045,394.

CRAWFORD, T. V. 1964*a*. Analysis of area influenced by wind machines in frost protection. Amer. Soc. Agr. Eng. Trans. ASME **7**:250–51, 255.

——— 1964*b*. Computing the heating requirements for frost protection. Jour. Appl. Meteor. **3**:750–60.

——— 1964*c*. Insulating value of tree wrapping materials. Unpub. mss. on file at the Dept. Agr. Eng., Univ. of Calif., Davis. 12 pp.

——— 1965. Frost protection with wind machines and heaters. Meteor. Monogr. **6**:(28):81–87.

CRAWFORD, T. V., and A. S. LEONARD. 1961. Orchard heater plume heights. Calif. Agr. **15**(8):13, **14**.

——— 1962. Observations of buoyant plumes in calm stably-stratified air. Jour. Appl. Meteor. **1**:251–56.

CREEL, J. M., JR., and E. O. OLSON. 1963. Cold damage to young navel orange trees on various rootstocks in freezes of 1962 and 1963 in the Winter Garden area of Texas. Proc. Rio Grande Val. Hort. Soc. **17**:55–59.

DARWIN, F. 1914. The effect of light on the transpiration of leaves. Proc. Roy. Soc. London, Ser. B, **87**: 281–99.

DATTA, B. 1918. On the non-stationary state of heat in an ellipsoid. Bul. Calcutta Math. Soc. **8**:87–118.

DAVIS, G. R. 1963. Influence of Santa Fe Lake on nearby minimum air temperatures. U. S. Dept. Commerce Weather Bur. Fed. State Frost Warning Serv. Lakeland, Fla. 6 pp. [Mimeo.]

DAVSON, H., and J. F. DANIELLI. 1943. The permeability of natural membranes. The Macmillan Co., New York. 364 pp.

DE BARR, A. E. 1948. The efficiency of radiation shields. Rev. Sci. Instr. **19**:569–73.

DE BOER, H. J. 1965. Comparison of water vapor, water and water drops of various sizes, as a means of preventing night frost. Agr. Meteor. **2**:247–58.

DESSENS, HENRI.. 1967. La grêle et sa prévention. Assn. d'Etudes des Moyens de Lutte contre Fléaux Atmosphériques, Toulouse, Rapport **15**:9–26.

DIEHL, H. C., and R. C. WRIGHT. 1924. Freezing injury of apples. Jour. Agr. Res. **29**:99–127.

DOBIE, J. B. 1948. Infra-red lights for frost protection. Address to Rural Electric Conference. Univ. Calif., Berkeley. 8 pp. [Mimeo.]

DURRENBERGER, R. W. 1956. Combating frost and winds. Calif. Citrog. **41**:243, 245–48, 418–19, 422–23.

DUSINBERRE, G. M. 1961. Heat-transfer calculations by finite differences. International Textbook Co., University Park, 293 pp.

ECKERT, E. R. G., and R. M. DRAKE, JR. 1959. Heat and mass transfer. McGraw-Hill Book Co., Inc., New York. 530 pp.

EGGERT, D. A. 1968. Use of liquid foam to prevent freeze injury to strawberry blossoms. HortScience **3**(1): 11–12.

EHRLER, W. L. 1971. Periodic nocturnal stomatal opening of citrus in a steady environment. Physiol. Plant. **25**:488–92.

ELSASSER, W. M. 1942. Heat transfer by infra-red radiation in the atmosphere. Harvard Univ. Blue Hill Meteorological Observatory. Milton, Mass. 107 pp.

ELSASSER, W. M., and M. F. CULBERTSON. 1960. Atmospheric radiation tables. Meteor. Monogr. **4**(23): 43 pp.

ERICKSON, L. C., B. L. BRANNAMAN, H. Z. HIELD, and M. D. MILLER. 1952. Responses of orange and grapefruit trees to maleic hydrazide. Bot. Gaz. **114**: 122–30.

FAVREAU, R. F., and G. G. GOYER. 1967. The effect of shock waves on the hailstone model. Jour. Appl. Meteor. **6**(2):326–35.

FARRALL, A. W., W. H. SHELDON, and C. HANSEN. 1946. Protection of crops from frost damage through the use of radiant energy. Mich. Agr. Expt. Sta. Quart. Bul. **29**:53–63.

FAWCETT, H. S. 1936. Citrus diseases and their control. Second edition. McGraw-Hill Book Co., Inc. New York. 656 pp.

FAWCETT, H. S., L. J. KLOTZ, and A. R. C. HAAS. 1933. Water spot and water rot of citrus fruits. Calif. Citrog. **18**:165, 175.

FORD, H. W. 1963. Effects of freeze injury on root distribution of citrus. Citrus Veg. Mag. **26**(6):24–25.

FOSTER, D. S. 1961. Aviation hail problem. World Meteor. Organ. Tech. Note **37**: 41 pp.

FOSTER, D. S., and F. C. BATES. 1956. A hail size forecasting technique. Bul. Amer. Meteor. Soc. **37**: 135–41.

FRIEDMAN, D. G. 1959. A frost survey of the Coachella Valley in southern California. Travelers Insurance Company, Weather Research Center. Occasional Papers in Meteorology, Hartford, Conn. 136 pp. [Mimeo.]

FRITZ, SIGMUND. 1957. Solar energy on clear and cloudy days. Sci. Mon. **84**:55–65.

FUCIK, J. E., and R. A. HENSZ. 1966. New insulating materials to protect citrus trees from freezing. Proc. Rio Grande Val. Hort. Soc. **20**:43–49.

FURR, J. R., R. T. BROWN, and E. O. OLSON. 1966. Relative cold tolerance of progenies of some citrus crosses. Proc. Rio Grande Val. Hort. Soc. **20**: 109–12.

FURR, J. R., and C. A. TAYLOR. 1939. Growth of lemon fruits in relation to moisture content of soil. U. S. Dept. Agr. Tech. Bul. **640**: 72 pp.

GANE, R. 1936. Thermal conductivity of the tissue of fruits. Rep. Food Investors Board, Sci. and Indus. Res. London. Pp. 211–12.

GARNIER, B. J., and A. OHMURA. 1968. A method of calculating the direct shortwave radiation income of slopes. Jour. Appl. Meteor. **7**:796–800.

GARRISON, J. B., and A. W. LAWSON. 1948. Extension of De Barr's analysis of radiation shielding. Rev. Sci. Instr. **19**:574–77.

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Original from PENN STATE

GARTHWAITE, J. W. 1914. Letter on frost and frost prevention. U. S. Dept. Agr. Mon. Weather Rev. **42**: 571–72.

GATES, D. M., and C. M. BENEDICT. 1963. Convection phenomena from plants in still air. Amer. Jour. Bot. **50**:563–73.

GATES, D. M., and W. TANTRAPORN. 1952. The reflectivity of deciduous trees and herbaceous plants in the infra-red to 25 microns. Science **115**:613–16.

GEIGER, R. 1965. The climate near the ground. Harvard Univ. Press, Cambridge, Mass. 611 pp.

GERBER, J. F. 1964. The use of heating devices for cold protection. Proc. Fla. State Hort. Soc. **77**:93–100.

——— 1966. Solid fueled grove heaters. Proc. Fla. State Hort. Soc. **79**:45–53.

——— 1969*a*. Petroleum coke heaters *vs* conventional heaters. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. **II**:535–38. Univ. Calif., Riverside, Calif.

——— 1969*b*. Methods of determining nocturnal heat requirements of citrus orchards. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. **II**:545–550. Univ. Calif., Riverside, Calif.

GERBER, J. F., and J. D. MARTSOLF. 1965. Protecting citrus from cold damage. Fla. Agr. Expt. Sta. Circ. **287**: 29 pp.

GERLOFF, E. D., T. RICHARDSON, and M. A. STAHMANN. 1966. Changes in fatty acids of alfalfa roots during cold hardening. Plant Physiol. **41**:1280–84.

GIRTON, R. E. 1927. The growth of citrus seedlings as influenced by environmental factors. Univ. Calif. Publ. Agr. Sci. **5**:83–117.

GORDON, H., and F. A. BROOKS. 1940. Infra-red lights fail to give immediate frost protection. Calif. Citrog. **25**:350, 372–73.

GOSS, J. R., and F. A. BROOKS. 1956. Constants for empirical expressions for downcoming atmospheric radiation under cloudless sky. Jour. Meteor. **13**: 482–88.

GRABLE, G. W. 1939. The combination of heat and wind machines. The Conveyor Co., Inc., Los Angeles. 2 pp. [Mimeo.]

GREGORY, F. G., F. L. MILTHORPE, H. L. PEARSE, and H. J. SPENCER. 1950. Experimental studies of the factors controlling transpiration. II. The relation between transpiration rate and leaf water content. Jour. Exptl. Bot. **1**:15–28.

GRIERSON, W. 1964*a*. Grove heating: Some thermodynamic considerations. Citrus Veg. Mag. **28**(4):22–25.

——— 1964*b*. Grove heating: Some thermodynamic considerations. Proc. Fla. State Hort. Soc. **77**:87–93.

GRIFFITHS, J. T., and C. H. HENDERSHOTT. 1961. Wind machine experience in Florida citrus groves, 1958–61. Citrus Indus. **42**(12):11–13, 15, 20.

GURNEY, H. P., and J. LURIE. 1923. Charts for estimating temperature distributions in heating or cooling solid shapes. Indus. Eng. Chem. **15**:1170–72.

GUSTAFSON, C. D. 1952. Frost protection for young trees. Calif. Citrog. 37:135.

HALL, A. D. 1915. The soil, an introduction to the scientific study of the growth of crops. E. P. Dutton and Company, New York. 311 pp.

HAMILTON, W. W. 1955. History of wind machines. National Frost Protection Co., Inc., Burbank, Calif. to Yuma Citrus Men's Club. 6 pp. [Mimeo.]

HANSON, K. J. 1963. The radiative effectiveness of plastic films for greenhouses. Jour. Appl. Meteor. **2**:793–97.

HARRISON, D. S., and J. F. GERBER. 1966. Propane fueled heaters for cold protection. Proc. Fla. State Hort. Soc. **79**:41–45.

HASSLER, F. J., C. L. HANSEN, and A. W. FARRALL. 1947. Protection of crops from frost damage by use of radiant energy-Part II. Mich. Agr. Expt. Sta. Quart. Bul. **30**:21–28.

——— 1948. Protection of vegetation from frost damage by use of radiant energy. Part III. Mich. Agr. Exp. Sta. Quart Bul. **30**:339–60.

HAWKINS, L. A., G. F. TAYLOR, W. R. BARGER, S. J. DENNIS, and W. V. HUKILL. 1949. Freezing of citrus fruits in California. Unpublished mss. from U. S. Dept. Agr., Hyattsville, Md. 29 pp.

HEARN, C. J., W. C. COOPER, and R. O. REGISTER. 1963. The influence of variety and rootstock upon freeze injury to citrus trees in the 1962 Florida freeze. Florida Citrus Comm. Freeze Eval. Comm. Special Rept., Orlando, Fla., 35 pp.

HEARN, C. J., W. C. COOPER, R. O. REGISTER, and R. YOUNG. 1963. Influence of variety and rootstock upon freeze injury to citrus trees in the 1962 Florida freeze. Proc. Fla. State Hort. Soc. **76**:75–81.

HEMBREE, G. D. 1958. Effect of the state of the ground on the local heat balance. U. S. Dept. Agr. Mon. Weather Rev. **86**:171–76.

HENDERSHOTT, C. H. 1962. The influence of maleic hydrazide on citrus trees and fruits. Proc. Amer. Soc. Hort. Sci. **80**:241–46.

HENSZ, R. A. 1969. Petroleum coke fuel blocks: Alone and with wind machines. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. **II**:529–33. Univ. Calif., Riverside, Calif.

HILGEMAN, R. H. 1963. Memorandum on frost damage in the Salt River Valley, Arizona. Unpublished notes on file in the Dept. of Biochemistry, Univ. Calif., Riverside, Calif. Jan. 31, 1963. 4 pp.

HILGEMAN, R. H., C. E. EVERLING, and J. A. DUNLAP. 1964. Effect of wind machines, orchard heaters and irrigation water on moderating temperatures in a citrus grove during severe freezes. Proc. Amer. Soc. Hort. Sci. **85**:232–44.

HILGEMAN, R. H., and L. H. HOWLAND. 1956. Report on the frost situation and effect of a wind machine on temperatures during 1954–55. Rept. Ariz. Citrus Inst. **1**:1–7.

HITSCHFELD, W., and M. STANDER. 1967. Temperature of hailstones. Jour. Atomic Sci. **24**:293–97.

HODGSON, R. W. 1933. Resistance to low winter temperatures of subtropical fruit plants. Proc. Amer. Soc. Hort. Sci. 30:349–54.

HOFFMAN, A. H. 1927. Laboratory tests of orchard heaters. Calif. Agr. Expt. Sta. Bul. **442**: 37 pp.

HOGE, W. P. 1919. The terrific windstorm on Mount Wilson, Cal., Nov. 24–26, 1918. U. S. Dept. Agr. Weather Rev. **47**:28.

HOON, P. 1966. Orchard heating. Red hot topic of summer tour. West. Fruit Grow. **20**(7):**16**.

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Original from PENN STATE

HORANIC, G., and G. YELONSKY. 1969. Electrostatic heating of citrus trees. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. **II**:539–44. Univ. Calif., Riverside, Calif.

HORN, C. W. 1937. (ed.). A manual for citrus growers. Mutual Orange Distributors, Redlands, Calif. 103 pp.

HUME, H. H. 1907. Citrus fruits and their culture. Orange Judd Co., New York, 382 pp.

——— 1926. The cultivation of citrus fruits. The Macmillan Co., New York. 561 pp.

HUMPHREYS, W. J. 1914. Frost protection. U. S. Dept. Agr. Mon. Weather Rev. **42**:562–69.

ILJIN, W. S. 1953. Causes of death of plants as a consequence of loss of water: conservation of life in desiccated tissues. Bul. Torrey Bot. Club **80**:166–77.

IVANOV, S. M. 1939. Activity of growth processes-principal factor in frost resistance of plants. Akademiia Nauk USSR. Comptes Rendus [Doklady], N. S., **22**:277–81.

JACKSON, L. K. 1963*a*. Late pruning of freeze-damaged citrus. Citrus Veg. Mag. **27**(3):28.

——— 1963*b*. Now is the time to stop pruning freeze-damaged citrus trees. Citrus Veg. Mag. **26**(12):13.

JAKOB, M. 1949. Heat transfer. **I**: 758 pp. John Wiley & Sons, Inc., New York.

JAKOB, M., and G. A. HAWKINS. 1957. Elements of heat transfer. John Wiley & Sons, Inc. New York. 317 pp.

JENNINGS, B. 1966. Shelter for orchard thermometers. West. Fruit Grow. **20**(7):25.

JENSEN, M. 1954. Shelter effect; investigations into the aerodynamics of shelter and its effects on climate and crops. The Danish Technical Press, Copenhagen. 264 pp.

JOHNSON, W. O. 1963. The big freeze of December, 1962. U. S. Dept. Commerce Weather Bur. Fed. State Frost Warning Serv., Lakeland, Fla. 32 pp. [Mimeo.]

JOHNSTON, J. C. 1939*a*. The use of blowers for frost protection. Calif. Citrog. **24**:354, 370–71.

——— 1939*b*. The effect of orchard heating on yield of Valencia oranges. Calif. Citrog. **24**:318.

——— 1949. Citrus tree damage in 1949. Calif. Citrog. **34**(6):266–67.

——— 1963. Treatment of frost-injured trees. Calif. Citrog. **48**:106, 116–17, 119.

JONES, W. W., M. J. GARBER, and J. E. NEWMAN. 1966. A 30-year record of solar radiation. Univ. Calif. Agr. Expt. Sta. Leaflet 193.

KAUP, C. H. 1937. Piping oil to heaters. Calif. Citrog. **22**: 302.

KEPNER, R. A. 1940. Operation of orchard heaters. Calif. Agr. Expt. Sta. Bul. **643**: 34 pp.

——— 1950. The principles of orchard heating. Calif. Agr. Expt. Sta. Circ. **400**: 10 pp.

——— 1951. Effectiveness of orchard heaters. Calif. Agr. Expt. Sta. Bul. **723**: 30 pp.

KHIDASHELI, A. N., G. B. NADARAYA, and Y. N. LOMIYA. 1959. Experiments in heating lemon trees under gauze covers by flameless and smokeless briquettes. Biol. Abstr. **46**:26910.

KIMBALL, H. H., and F. D. YOUNG. 1920. Smudging as a protection from frost. U. S. Mon. Weather Rev. **48**:461–62.

KLOTZ, L. J. 1961. Color handbook of citrus diseases. Univ. Calif. Press, Berkeley and Los Angeles. 74 pp.

KLOTZ, L. J., A. M. BOYCE, H. D. CHAPMAN, G. E. CARMAN, C. CREE, W. W. JONES, L. A. RIEHL, W. B. SINCLAIR, E. R. PARKER, W. S. STEWART, and F. M. TURRELL. 1949. Water spot on navel oranges. Calif. Citrog. **34**:122–26.

KLOTZ, L. J., T. A. DE WOLFE, F. M. TURRELL, R. G. PLATT, and M. P. MILLER. 1968. Concentric ring stipple of grapefruit. Calif. Citrog. **53**:154–56.

KNORR, L. C., R. F. SUIT, and E. P. DU CHARME. 1957. Handbook of citrus diseases in Florida. Fla. Agr. Expt. Sta. Bul. **587**: 157 pp.

KONRAD, DWAYNE. 1964. Gas burners. Calif. Citrog. **49**: 211.

KRETCHMAN, D. W., and P. J. JUTRAS. 1964. The relationship of pruning for invigoration to freeze damage of mature citrus trees. Citrus Indus. **45**(5):11, 13–14.

KRICK, I. P. 1939. A physical basis for long range weather forecasting. Calif. Citrog. **24**:100–01, 106.

KUIPER, P. J. C. 1964. Inducing resistance to freezing and desiccation in plants by decenylsuccinic acid. Science. **146**:544–46.

——— 1969. Surface-active chemicals, membrane permeability, and resistance to freezing. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. **II**: 593–94. Univ. Calif., Riverside, Calif.

LAMADE, W. 1967. Yakima Valley orchard heating tour. West. Fruit Grower. **21**(7):9–10.

LANGE, N. A. 1939. Handbook of chemistry. Handbook Publishers, Inc., Sandusky, Ohio. 249 pp.

LANGHAAR, H. L. 1951. Dimensional analysis and the theory of models. John Wiley and Sons, Inc., New York. 166 pp.

LAWLESS, W. W. 1941. Effect of freeze damage on citrus trees and fruit in relation to grove practices. Proc. Fla. State Hort. Soc. **54**:67–74.

LAWLESS, W. W. and A. F. CAMP. 1940. Preliminary report on varieties and other factors as influencing cold resistance in citrus. Proc. Fla. State Hort. Soc. **53**:120–25.

LAWRENCE, F. P. 1963*a*. February treatment of cold-injured citrus trees. Citrus Veg. Mag. **26**(6):12–14, 16, 18, 26.

——— 1963*b*. March treatment of cold-injured trees. Citrus Veg. Mag. **26**(7):8.

LAWSON, A. W., and R. FANO. 1947. Note on the efficiency of radiation shields. Rev. Sci. Instr. **18**(10):727–29.

LEE, R. 1973. The "Greenhouse" Effect. Jour. Appl. Meteor. **12**:556–57.

LEE, R. E. 1972. The size of suspended particulate matter in air. Science **178**:567–75.

LEGGETT, J. T., and G. E. SUTTON. 1951. Precooling of citrus fruit. Eng. Prog. **5**(5): 31 pp.

LEONARD, A. S. 1951. The return-stack orchard heater. Agr. Eng. **32**:655–56.

——— 1953. Demonstration of low-power test stand to determine propeller coefficients. Univ. Calif., Wind Machine Conf., Davis, Calif. [Mimeo.]

LEONARD, A. S., and L. M. K. BOELTER. 1942. Some effects of inert diluents on the combustion of hydrocarbon fuels. Ann. Proc. Pacific Coast Gas Assoc. (Eng. Ed.) **33**:73–82.

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Original from PENN STATE

LEVITT, J. 1956. The hardiness of plants. Academic Press, Inc., New York. 278 pp.
——— 1957. The moment of frost injury. Protoplasma 48:289–302.
——— 1958. Frost, drought and heat resistance. *In:* Heilbrunn, L., and F. Weber. Protoplasmatologia. Handbuch Protoplasma Forsch. 8(6): 87 pp.
——— 1962. A sulfhydryl-disulfide hypothesis of frost injury and resistance in plants. Jour. Theoret. Biol. 3:355–91.
LEVY, F. 1967. L. P. gas heaters. Private communication.
LEYDEN, R. F. 1957. Bank citrus trees in summer months. Texas Farm. Citricult. 34(1):4.
——— 1964*a*. Herbicides around newly-planted citrus trees. Proc. Rio Grande Val. Hort. Soc. 18:21–24.
——— 1964*b*. Chemical weed control with no tillage: A cultural practice for Texas citrus orchards. Proc. Rio Grande Val. Hort. Soc. 18:25–28.
LEYDEN, R. F., R. A. HENSZ, and J. E. FUCIK. 1965. Under-the-tree heating tests in citrus orchards using petroleum coke fuel blocks. Proc. Rio Grande Val. Hort. Soc. 19:54–60.
——— 1966. Citrus orchard heating with petroleum coke fuel. Proc. Rio Grande Val. Hort. Soc. 20:39–42.
LEYDEN, R. F., and P. W. ROHRBAUGH. 1963. Protection of citrus trees from cold damage. Proc. Amer. Soc. Hort. Sci. 83:344–351.
LIST, R. J. 1963. On the effect of explosion waves on hailstone models. Jour. Appl. Meteor. 2:494–97.
LIST, R. J. 1966. Smithsonian meteorological tables. Smithson. Misc. Coll. 114:527 pp.
LOVELOCK, J. E., and M. W. H. BISHOP. 1959. Prevention of freezing damage to living cells by dimethyl sulphoxide. Nature 183:1394–5.
LUCAS, J. W. 1953. Tests on freezing lemons. Preliminary experiments on subcooling and freezing in lemons seek mechanism of ice initiation and spread. Calif. Agr. 7(11):9–10.
——— 1954. Subcooling and ice nucleation in lemons. Plant Physiol. 29:245–51.
LUDLAM, F. H. 1958. The hail problem. Nubila 1(1):12–96.
LURIE, M., and N. MICHAILOFF. 1936. Evaporation from free water surface. Indus. Eng. Chem. 28:345–49.
LYONS, J. M., T. A. WHEATON, and H. K. PRATT. 1964. Relationship between the physical nature of mitochrondrial membranes and chilling sensitivity in plants. Plant Physiol. 39(2):262–68.
MCADAMS, W. H. 1954. Heat transmission. Third edition. McGraw-Hill Book Co., Inc. New York. 532 pp.
MCADIE, A. G. 1901. Frost fighting. U. S. Dept. Agr. Mon. Weather Rev. 29:65–67.
——— 1912. Climatological data for Dec. 1912, District No. 11, California, U. S. Dept. Agr. Mon. Weather Rev. 40:1881.
MACLEAN, J. D. 1930. Studies of heat conduction in wood. Results of steaming green round southern pine timbers. Proc. Amer. Wood Preserv. Assoc. 26: 197–219.
——— 1946. Rate of temperature change in short-length round timbers. Amer. Soc. Mech. Eng. Trans. 68: 1–16.
MARTH, P. C. 1965. Increased frost resistance by application of plant growth-retardant chemicals. Jour. Agr. Food Chem. 13:331–33.
MARTIN, E. 1943. Studies of evaporation and transpiration under controlled conditions. Carnegie Inst. Wash. Pub. 550: 48 pp.
MARTIN, GEORGE C., and L. P. BATJER. 1968. A system for controlling the night temperature of fruit trees. Hort. Sci. 3(1):13–14.
MARVIN, C. F. 1941. Psychrometric tables for obtaining the vapor pressure, relative humidity, and temperature of the dew point. U. S. Dept. Comm. Weather Bur. 235: 87 pp.
MAXWELL, N. P. 1967. Cold tolerance of several citrus varieties and strains on sour orange rootstock during a freeze in December 1966 at Crystal City, Texas. Proc. Rio Grande Val. Hort. Soc. 21:68–73.
MAXWELL, N. P., and M. BAILEY. 1965. Cold protection of citrus by under-the-tree heating with petroleum wax heaters. Proc. Rio Grande Val. Hort. Soc. 19: 61–65.
MAXWELL, N. P., and A. SHULL. 1963. Influence of timing of fertilizer applications on yield, quality, and cold hardiness of red grapefruit in the Rio Grande Valley of Texas. Proc. Rio Grande Val. Hort. Soc. 17:68–71.
MAXWELL, N. P., and H. K. WUTSCHER. 1968. Freeze injury to young Fairchild and Bower tangerine trees on six rootstocks in the Winter Garden area. Proc. Rio Grande Val. Hort. Soc. 22:10–15.
MAZUR, P. 1965. Causes of injury in frozen and thawed cells. Proc. Fed. Amer. Soc. Exptl. Biol. Crybiol. 24(2): S–175–82, Part III, Suppl. 15.
MEISTER, RICHARD. 1967. Here's the latest in frost control. Amer. Fruit Grow. 87(3):11–14, 16, 50–51.
MERTZ, W. M. 1924. Windburning of citrus trees. Calif. Citrog. 9:85, 101, 103–04.
MICKE, W. C., J. A. BEUTEL, and J. T. YEAGER. 1966. Water base paints for sunburn protection of young fruit trees. Calif. Agr. 20(7):7.
MILLER, M. P. 1963*a*. Dry air a factor in sprinkling avocados for frost protection. Calif. Avoc. Soc. Yearbook 47:37–39.
——— 1963*b*. Sprinklers and frost protection. Calif. Citrog. 48: 267, 277–278.
——— 1968. Wrapping cold injured young trees helped minimize bark damage. Calif. Citrog. 53:404.
MILLER, M., and F. RUSSO. 1964. Studi sulla protezione Antigelo in Sicilia durante l'inverno 1963–64. Estratto dalla Rivista di Agrumicoltura, Acireale. Stazione Sperimental di Agrumicoltura e di frutticoltura.
MILLER, M. P., F. M. TURRELL, and S. W. AUSTIN. 1966. Solid fuel candletype orchard heaters. Calif. Agr. 20(3):2–4.
MILLIKEN, C. S., A. R. TYLOR, W. W. BONNS, and H. J. WEBBER. 1919. A study of the effects of freezes on citrus in California. I. A study of the freeze of 1913 in California. Calif. Agr. Expt. Sta. Bul. 304:249–98.
MIRSKY, A. E., and L. PAULING. 1936. On the structure of native, denatured and coagulated proteins. Proc. Nat. Acad. Sci. U. S. 22:439–47.
MODLIBOWSKA, I., and W. S. ROGERS. 1955. Freezing of plant tissues under the microscope. Jour. Exptl. Bot. 6:384–91.
MOSES, BEN D. 1938. Blowers for frost protection. Agr. Eng. 19:207–08.

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Original from PENN STATE

MYERS, V. A. 1947. An investigation of diurnal temperature changes. M. S. Thesis on file at Massachusetts Institute of Technology Library. 119 pp.

NEIBURGER, M. 1941. Insolation and the prediction of temperatures. Bul. Amer. Meteor. Soc. **22**:95–102.

NEWCOMB, D. A. 1949. Operating orchard heaters under present cost conditions. Calif. Citrog. **34**:100, 136–37.

NEWMAN, J. E. 1971. Climatic changes: Some evidence and implications. Weatherwise **25**:56–62.

NEYMAN, J., E. L. SCOTT, M. A. WELLS, M. NEIBURGER, and H. C. CHIN. 1968. Influence of atmospheric stability layers on effect of ground-based cloud seeding. Proc. Nat. Acad. Sci. **60**(2):416–31.

NIVEN, C. 1880. V. On the conduction of heat in ellipsoids of revolution. Phil. Trans. Roy. Soc. [London] **171**: 117–51.

NIXON, H. W. (ed.). 1949. The freeze of 1949. The Lemon Men's Club Forum Sunkist Bldg., Los Angeles, Calif. 28 pp. [Mimeo.]

NORRIS, R. E. 1963. Fall management practices in cold injured groves. Citrus Indus. **44**(8):5–6.

NORTH, C. P., and A. WALLACE. 1955. Soil temperature and citrus. Low soil temperature contributes to low number of roots under citrus trees in some areas of southern California. Calif. Agr. **9**(11):13.

NUTT, K. J. 1959. Original historical material on wind machines in California; press releases, blueprints, patents. National Frost Protection Co., Inc., Burbank, Calif.

OLSON, E. O., and N. MAXWELL. 1964. Tangerine and tangerine-hybrid varieties for Texas. Proc. Rio Grande Val. Hort. Soc. **18**:44–50.

OLSON, F. C. W., and J. M. JACKSON. 1942. Heating curves, theory and practical applications. Indus. Eng. Chem. **34**:337–41.

OPITZ, K. 1965. Frost protection survey summary. Citrus notes. Univ. Calif. Agr. Ext. Serv., Tulare Co. 1 pp.

ÖRSKOV, S. L. 1934. Untersuchungen uber den Einfluss von Kohlensäure und Blei auf die Permeabiltat der Blut korperchen fur Kalium und Rubidium. Biochem. Zeitschr **279**:250–61.

PALMER, T. Y. 1969. Physical characteristics of acetyl-alcohol fog for frost protection. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. **II**:579–82. Univ. Calif., Riverside, Calif.

PARKER, R. A. 1964. Rehabilitating freeze-damaged trees. Citrus Indus. **45**:23–24.

PARKHURST, D. F., P. R. DUNCAN, D. M. GATES, and F. KREITH. 1968. Wind-tunnel modelling of convection of heat between air and broad leaves of plants. Agr. Meteor. **5**:33–47.

PATTON, T. C. 1944. Graphical methods for temperature distribution with unsteady heat flow. Indus. Eng. Chem. **36**:990–96.

PERRY, R. L., and W. P. BERGGREN. 1944. Transient heat conduction in hollow cylinders after sudden change of intersurface temperature. Univ. Calif. Pub. Eng. **5**:59–88.

PERRY, R. L., F. M. TURRELL, and S. W. AUSTIN. 1964. Thermal diffusivity of citrus fruit. *In:* Johnson, H. A. (ed.). Heat transfer, thermodynamics, and education. pp. 242–46. McGraw-Hill Book Co., Inc., New York. 472 pp.

PEYNADO, A., and R. H. YOUNG. 1963. Toxicity of three salts to greenhousegrown grapefruit trees and their effects on ion accumulation and cold hardiness. Proc. Rio Grande Val. Hort. Soc. **17**:60–67.

PEYNADO, A., R. H. YOUNG, and W. C. COOPER. 1963. A comparison of three major Texas freezes and a description of tissue temperature of Valencia orange tree parts during the January 9 to 12, 1962 freeze. Proc. Rio Grande Val. Hort. Soc. **17**:15–23.

PIPKIN, O. A., and C. M. SLIEPCEVICH. 1964. Effect of wind on buoyant diffusion flames. Indus. Eng. Chem. Fund. 3(2):147–54.

PLATT, R. 1965. Natural gas for orchard heating. Personal communication, May 19, 1965.

POPPENDIEK, H. F. 1949. Net radiant heat transfer between two infinite parallel planes separated by an infinitely thin perforated radiation shield. Part II p. II–3: *In:* An investigation of several orchard heating problems. Unpublished Ph.D. thesis on file at the University of California, Los Angeles.

——— 1953. Transient and steady state heat transfer in irradiated citrus fruit. Amer. Soc. Mech. Eng. Trans. 421–25.

PUFFER, R. E., and F. M. TURRELL. 1967. Frost protection in citrus. Univ. Calif. Agr. Ext. Serv. AXT-108. Berkeley Revision. 9 pp.

RACKHAM, R. L. 1965. Frost injury to young citrus trees. Citrus Notes **4**:960*c*. Univ. Calif. Agr. Ext. Serv., Tulare Co.

RASCHKE, K. 1960. Heat transfer between the plant and the environment. Ann. Rev. Plant Physiol. **11**:111–26.

REED, H. S. 1930. The swelling of citrus fruits. Amer. Jour. Bot. **17**:971–82.

REED, H. S., and E. T. BARTHOLOMEW, 1930. The effects of desiccating winds on citrus trees. Calif. Agr. Expt. Sta. Bul. **484**:59 pp.

REITZ, H. J. 1963*a*. Rehabilitation. Notes on care of cold-damaged groves. Citrus Veg. Mag. **26**(5):12, 14.

——— 1963*b*. Further notes on care of cold-damaged groves. Citrus Veg. Mag. **26**(6):12–14, 16, 18.

REUTHER, W., and P. F. SMITH. 1954. Effect of method of timing nitrogen fertilization on yield and quality of oranges. Proc. Fla. State Hort. Soc. **67**:20–26.

RIEHL, L. A., and G. E. CARMAN. 1953. Water spot on navel oranges. Calif. Agr. **7**(10):7–8.

RIEHL, L. A., and C. W. COGGINS. 1964. Influence of Gibberellin A_3 on navel orange water spot. Univ. Calif. Res. Center, Riverside, Progress Rept. 2 pp. [Mimeo.]

RIDDELL, J. A., H. A. HAGEMAN, C. M. J. ANTHONY, and W. L. HUBBARD. 1962. Retardation of plant growth by a new group of chemicals. Science **136**:391.

ROHRBAUGH, P. W. 1956. Permanent tree banks. Texas Farm. Citricult. **33**(6):4.

——— 1962. Texas Roundup—'One half million boxes—maybe.' Citrus Veg. Mag. **25**(8):17–18.

ROHRBAUGH, P. W. 1963. Private communication.

ROHRBAUGH, P. W., and R. F. LEYDEN. 1958. Tree banks are freeze tested. Texas Farm. Citricult. **34**(9):20.

ROGERS, W. J., and H. L. SWIFT. 1970. Frost and the prevention of frost damage. U. S. Dept. of Commerce National Oceanic Atmospheric Administration, Washington, D.C. 35 pp.

SAKAI, A. 1968. Mechanism of desiccation damage of forest trees in winter. Contrib. Inst. Low Temp. Sci., Ser. B, 1(15):15–35.

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SALT, R. W. 1961. Principles of insect cold-hardiness. Ann. Rev. Ent. 6:55–74.
SAVAGE, Z. 1963. Consider intersetting badly cold damaged trees. Citrus Veg. Mag. 26(11):16, 19–20.
SCHNEIDER, H. 1955. Ontogeny of lemon tree bark. Amer. Jour. Bot. 42:893–95.
SCHOONOVER, W. R., F. A. BROOKS, and H. B. WALKER. 1939. Protection of orchards against frost. Univ. Calif. Agr. Ext. Serv. Circ. 111: 70 pp.
SCHOONOVER, W. R., and R. W. HODGSON. 1925. Orchard heating in California. Calif. Agr. Expt. Sta. Bul. 398: 69 pp.
SCHOONOVER, W. R., R. W. HODGSON, and F. D. YOUNG. 1930. Frost protection in California orchards. Calif. Agr. Ext. Serv. Circ. 40: 73 pp.
SCOTT, G. N. 1937. Protection of orchard heater pipe lines against corrosion. Calif. Citrog. 22:354, 357.
SHADBOLT, C. A., O. D. MCCOY, and T. M. LITTLE. 1961. Soil temperatures as influenced by bed direction. Proc. Amer. Soc. Hort. Sci. 78:488–95.
SHAMEL, A. D. 1937. Frost injury to bearing orange trees. Calif. Citrog. 22:290, 307.
SHARP, L. T. 1937. Freeze observations and after treatment of citrus orchards. Calif. Citrog. 22:394, 416–17, 432–35.
SHIFTAN, S. L. 1945. Frost injury to citrus fruits and the conditions favoring its occurrence in Palestine. Palestine Jour. Bot. [Rehovot] 5:96–105.
SHULER, P. E., and E. F. SCARBOROUGH. 1964. Florida agricultural statistics citrus summary for 1964. Fla. Dept. Agr. 43 pp.
SHULER, P. E., J. W. TODD, and E. F. SCARBOROUGH. 1971. Florida agricultural statistics, citrus summary for 1971. Fla. Dept. Agr. 46 pp.
SHULL, A. 1968. Split bark repair of freeze damaged trees in 1962. Personal communication.
SIMPSON, R. R. 1963. Four freeze seasons compared. Calif. Citrog. 48(12):422–23.
——— 1964. Private communication. U. S. Weather Bur. Fruit Frost Serv., Pomona, Calif.
SMALL, R. T. 1949. The use of wind machine and helicopter flights for frost protection. Bul. Amer. Meteor. Soc. 30:79–85.
SMITH, W. 1924. Wind damage and its prevention. Calif. Citrog. 9:124, 144.
STEPHENS, E. R., and M. R. PRICE. 1972. Comparison of synthetic and smog aerosols. Jour. Colloid Interface Sci. 39:272–86.
STERN, A. C. 1962. (ed.). Air Pollution. Vol. I. Academic Press, New York. [*See specifically:* pp. 231, 247.]
STEWARD, F. C. 1965. Stephen Hales Award Lecture. Amer. Soc. Plant Physiol. Ann. Meeting, Univ. Ill., Urbana.
STEWART, I., and C. D. LEONARD. 1960. Increased winter hardiness in citrus from maleic hydrazide sprays. Proc. Amer. Soc. Hort. Sci. 75:253–56.
STRAUSS, M. W. 1954. Water loss investigation: Lake Hefner Studies, Technical Report. Geol. Surv. Prof. Pap. 269: 158 pp.
STUGARD, B., and J. H. BURKE. 1962. January freeze hurts Mexican citrus. U. S. Dept. Agr. For. Agr. Serv. FCF 3–62: 17 pp.
SUTTER, C. 1962. Ceramic blocks for gas-fueled infrared orchard heat. Private communication.
SUTTON, O. G. 1953. Micrometeorology. McGraw-Hill Book Co., Inc., New York. 333 pp.
TEAGUE, C. C. 1944. Fifty years a rancher. The Ward Ritchie Press, Los Angeles, Calif. 199 pp.
THOMPSON, D. J. 1937. Survey of wind machines under freeze conditions. Calif. Citrog. 22:208–10.
THUT, H. F. 1938. Relative humidity variations affecting transpiration. Amer. Jour. Bot. 25:589–95.
——— 1939. The relative humidity gradient of stomatal transpiration. Amer. Jour. Bot. 26:315–19.
TOWT, W. 1922. Frost prevention and some facts about the Cobb temperature regulator. Lindsay, Exeter, Visalia News. Oct. 6., p. 3.
TRUESDAIL LABORATORIES, INC. 1967. Heat transmission study, oil fired orchard heater. Report sent to Spot Heaters, Inc. Sunnyside, Wash. 29 pp.
TURRELL, F. M. 1936. The area of the internal exposed surface of dicotyledon leaves. Amer. Jour. Bot. 23:255–64.
——— 1964. Internal surface-intercellular space relationships and the dynamics of humidity maintenance in leaves. *In:* Amdure, E. J. (ed.). International symposium on humidity and moisture. II: 39–53. Reinhold Publishing Corp., New York.
TURRELL, F. M., and S. W. AUSTIN. 1958. Wind machine operations prior to and following freezing temperatures as protection against freeze injury in citrus groves. Project 1731. Calif. Agr. Expt. Sta., Riverside, Calif.
TURRELL, F. M., and S. W. AUSTIN. 1960*a*. Factors influencing wind machine operation. Calif. Citrog. 46:38, 52–54.
——— 1969. Thermal conductivity and mass in stems, leaves, and fruit in relation to frost resistance. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. II:601–08. Univ. Calif., Riverside.
——— 1960*b*. Recovery from freeze injury by citrus. Calif. Agr. 14(7):9–10.
——— 1965. Comparative nocturnal thermal budgets of large and small trees. Ecology 46:25–34.
TURRELL, F. M., S. W. AUSTIN, D. MCNEE, and W. J. PARK. 1967. Thermal conductivity of functional citrus tree wood. Plant Physiol. 42:1025–34.
TURRELL, F. M., S. W. AUSTIN, and R. L. PERRY. 1960*a*. Frost control. West. Fruit Grow. 14(9):21–22.
——— 1960*b*. Temperature control in orchards. Yearbook Calif. Macadamia Soc. 6:51–58.
——— 1961. Water, heaters, and wind machines. Calif. Citrog. 46(5):154, 156, 158, 160.
——— 1962. Nocturnal thermal exchange of citrus leaves. Amer. Jour. Bot. 49:97–109.
——— 1965*a*. Nine years of frost? Calif. Citrog. 5:258, 268, 270, 272.
——— 1965*b*. Frost protection by lakes and reservoirs. Unpublished memos on file at Dept. of Biochem., Univ. of Calif., Riverside, Calif.
TURRELL, F. M., S. W. AUSTIN, R. L. PERRY, and F. A. BROOKS. 1958. Recovery of citrus from freezing. Calif. Citrog. 43:151, 162.
TURRELL, F. M., and A. M. BOYCE. 1953. Effect of quality and intensity of solar radiation on injury of lemon fruit by sulphur treatment in the field. Plant Physiol. 28:151–76.
TURRELL, F. M., M. CHERVENAK, and A. P. VANSELOW. 1952. Inorganic composition of exudate from Eureka lemons treated with elemental sulfur dust. Amer. Jour. Bot. 39:693–99.

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Original from PENN STATE

TURRELL, F. M., and L. J. KLOTZ. 1940. Density of stomata and oil glands and incidence of water spot in the rind of Washington navel orange. Bot. Gaz. **101**:862–71.

TURRELL, F. M., J. ORLANDO, and S. W. AUSTIN. 1964. Researchers forge link between rind-oil spot and foggy weather. West. Fruit Grow. **18**(9):17–18.

TURRELL, F. M., G. M. PEAVY, and S. W. AUSTIN. 1967. New solid fuels and thermal conductivity of leaves. Calif. Citrog. **52**:508, 510, 512, 514.

TURRELL, F. M., and R. L. PERRY. 1957. Specific heat and heat conductivity of citrus fruit. Proc. Amer. Soc. Hort. Sci. **70**:261–65.

TURRELL, F. M., R. L. PERRY, F. A. BROOKS, and S. W. AUSTIN. 1956. Wind machine operation prior to and following freezing temperatures as protection against freeze injury in citrus groves. Project 1731. Calif. Agr. Expt. Sta., Riverside, Calif.

——— 1957. Wind machine operation prior to and following freezing temperatures as protection against freeze injury in citrus groves. Project 1731. Calif. Agr. Expt. Sta., Riverside, Calif.

——— 1962. Convection, radiation, conduction, and mass heat transfer studies related to protection of citrus groves. Project 1731. Calif. Agr. Expt. Sta., Riverside, Calif.

——— 1963. Convection, radiation, conduction, and mass heat transfer studies related to protection of citrus groves. Project 1731. Calif. Agr. Expt. Sta., Riverside, Calif.

——— 1964. An analysis of wind in southern California freezes. Project 1731. Calif. Agr. Expt. Sta., Riverside, Calif.

——— 1965. Wind machine operation prior to and following freezing temperatures as protection against freeze injury in citrus groves. Project 1731. Calif. Agr. Expt. Sta., Riverside, Calif.

TURRELL, F. M., D. M. Ross, and K. IWATA. 1969. Thermal conductivity of agriculturally important plant materials. Unpublished memos on file at Dept. of Biochem., Univ. of Calif., Riverside, Calif.

TURRELL, F. M., and J. R. WEBER. 1955. Wind machine operation prior to and following freezing temperatures as a protection against freeze injury in citrus groves. Project 1731. Calif. Agr. Expt. Sta., Riverside, Calif.

UPHOF, J. C. TH. 1938. Wissenschaftliche beobachtungen und versuche an agrumen IX. Der einfluss von frost. Gartenbauwiss. **11**:391–412.

URE, C. R. 1969. A comparison of orchard heating systems. Presented at Sixth Annual Symp. Thermal Agr. Tech. Pap., Atlanta, Ga. 10 pp.

VAILE, R. S. 1924. A survey of orchard practices in the citrus industry of southern Calif. Calif. Agr. Expt. Sta. Bul. **374**: 40 pp.

VAN EIMERN, J., R. KARSCHON, L. A. RAZUMOVA, and G. W. ROBERTSON. 1964. Windbreaks and shelterbelts. World Meteor. Organ. Tech. Note **59**: 188 pp.

VASIL'YEV, I. M. 1961. Wintering of plants. Translated from the Russian by Royer and Roger, Inc. J. Levitt (ed.). Amer. Inst. Biol. Sci., Washington, D.C. 300 pp.

VITTORI, O. 1966. Comments on: the effect of explosion waves on hailstone models. Jour. Appl. Meteor. **5**:132–34.

WAYNICK, D. D. 1928. Factors concerned in the growth of Valencia orange. Calif. Citrog. **13**:200.

WEBBER, H. J. 1937*a*. Frost injury to citrus reduced by growth in date gardens. Calif. Citrog. **22**:270–71.

——— 1937*b*. Is whitewashing to prevent sunburn on frozen citrus trees a safe practice? Calif. Citrog. **22**:185, 214.

——— 1948. Plant characteristics and climatology. *In:* Webber, H. J., and L. D. Batchelor (eds.). The citrus industry. **I**:41–69. Univ. Calif. Press, Berkeley and Los Angeles.

WEBBER, H. J., and L. D. BATCHELOR. 1943. The citrus industry. Univ. Calif. Press, Berkeley and Los Angeles. 1,028 pp.

WEBER, R. L. 1941. Temperature measurement and control. The Blakiston Co., Philadelphia. 430 pp.

WHEATON, R. Z., and E. H. KIDDER. 1964. The effect of evaporation on frost protection by sprinkling. Mich. Agr. Expt. Sta. Quart. Bul. **46**:431–37.

WHITEMAN, T. M. 1957. Freezing points of fruits, vegetables and florist stocks. U. S. Dept. Agr. Market. Res. Rept. **196**: 32 pp.

WIEGAND, C., V. MYERS, and N. MAXWELL. 1966. Thermal patterns of solid fuel block-heated citrus trees. Proc. Rio Grande Val. Hort. Soc. **20**:21–30.

WIGHT, SAM V. 1939. Report on Aladdin Orchard Protector to the Univ. of Calif. (Dept. Agr.) Davis, Calif. Aladdin Mfg. Co., Los Angeles, Calif. 4 pp. [Mimeo.]

WILDER, H. J. 1948. Effects of freezes: treatment and recovery of injured trees. *In:* Batchelor, L. D., and H. J. Webber (eds.). The citrus industry. **II**:889–917. Univ. Calif. Press, Berkeley and Los Angeles.

WILLIAMS, P. F. 1911. The satsuma orange. Ala. Agr. Expt. Sta. Bul. **157**:143–74.

WILLIAMS, P., JR. 1964. Air Pollution potential over the Salt Lake Valley of Utah as related to stability and wind speed. Jour. Appl. Meteor. **3**:92–97.

WILLIAMSON, E. D., and L. H. ADAMS. 1919. Temperature distribution in solids during heating or cooling. Phys. Rev. **14**:99–114.

WOODRUFF, N. P. 1954. Shelter belt and surface barrier effects on wind velocities, evaporation, house heating, snow drifting. Kansas Agr. Expt. Sta. Tech. Bul. **77**: 27 pp.

WOODRUFF, N. P., D. W. FRYREAR, and L. LYLES. 1963. Reducing wind velocity with field shelter belts. Kansas Agr. Expt. Sta. Tech. Bul. **131**: 26 pp.

WOODRUFF, N. P., R. A. READ, and W. S. CHEPIL. 1959. Influence of a field windbreak on summer wind movement and air temperature. Kansas Agr. Expt. Sta. Tech. Bul. **100**: 24 pp.

WOODRUFF, N. P., and ZINGG, A. W. 1952. Wind-tunnel studies of fundamental problems related to windbreaks. U. S. Dept. Agr. Soil Cons. Ser. Tech. Pap. **112**: 25 pp.

WRATHER, W. E. 1954. Water-loss investigations: Lake Hefner Studies, Technical report. Geol. Surv. Prof. Pap. **269**: 158 pp.

WRIGHT, R. C., and G. F. TAYLOR. 1921. Freezing injury to potatoes when undercooled. U. S. Dept. Agr. Bul. **916**: 15 pp.

YATES, H. E. 1963. Temperature profile of south Florida windbreaks. Fed. State Frost Warn. Serv., Lakeland, Fla. 11 pp.

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YELENOSKY, G. 1966. Investigations of various heating methods for frost protection of Florida citrus trees. Citrus Veg. Mag. **29**(5):41.

YELENOSKY, G., R. O. REGISTER, and C. J. HEARN. 1965. Recovery of citrus trees injured in the 1962 Florida freeze. Citrus Indus. **46**(5):5–6, 16–17.

YELENOSKY, G., and G. HORANIC. 1966. The effect of different types of heaters used singly and in combination for freeze protection. Proc. Fla. State Hort. Soc. **79**:53–62.

——— 1969. Electrostatic heating of citrus trees. *In:* Chapman, H. D. (ed.). Proc. First Intern. Citrus Symp. **II**:539–44. Univ. Calif., Riverside, Calif.

YOUNG, F. D. 1922. Influence of cover crops on orchard temperature. USDA Mon. Weather Rev. **50**:521–26.

——— 1923. Carbon briquet orchard heaters. Calif. Citrog. **9**:44, 72.

——— 1924. Frost protection by artificial mixing of air. Calif. Citrog. **9**:125, 132, 136, 138.

——— 1925. A further study of the relation between cover crops and orchard temperatures. U. S. Dept. Agr. Mon. Weather Rev. **53**:387–391.

——— 1929. Frost and prevention of frost damage. U. S. Dept. Agr. Farm. Bul. **1588**: 62 pp.

——— 1938*a*. California orchard heater statistics. Calif. Citrog. **23**:371, 386, 388.

——— 1938*b*. The 1937 freeze in California. U. S. Dept. Agr. Weather Rev. **66**:311–24.

——— 1941. Frost and the prevention of frost damage. U. S. Dept. Agr. Farm. Bul. **1588**: 66 pp. [Revised.]

——— 1949. Notes on how to use a fruit thermometer. Calif. Citrog. **34**:99.

——— 1951. Firing Information. Calif. Citrog. **37**:3.

YOUNG, F. D., and W. E. HARMAN. 1948. Protecting the citrus orchard against frost. *In:* Batchelor, L. D., and H. J. Webber (eds.). The citrus industry. **II**: 847–87. Univ. Calif. Press, Berkeley and Los Angeles.

YOUNG, R. H. 1963*a*. Climate-cold hardiness-Citrus. Proc. Rio Grande Val. Hort. Soc. **17**:3–14.

——— 1963*b*. Freeze injury to four and nine-year-old citrus cultivars and related species in the lower Rio Grande Valley of Texas. Proc. Rio Grande Val. Hort. Soc. **17**:30–36.

——— 1963*c*. Freeze injury to young seedlings of citrus cultivars and related species in the lower Rio Grande Valley. Proc. Rio Grande Val. Hort. Soc. **17**:37–42.

——— 1963*d*. Pruning freeze-injured citrus trees in Texas. Citrus Veg. Mag. **26**(7):10, 12.

——— 1965. Microclimate temperatures of large and small citrus trees as affected by heat from LP gas heaters. Proc. Rio Grande Val. Hort. Soc. **19**:76–83.

YOUNG, R. H., H. DEAN, A. PEYNADO, and J. C. BAILEY. 1962. Effects of winter oil spray on cold hardiness of redblush grapefruit trees. Proc. Rio Grande Val. Hort. Soc. **16**:7–10.

YOUNG, R. H., J. E. FUCIK, and R. A. HENSZ. 1967. Tests of insulating materials for citrus tree trunk freeze protection using controlled freezing conditions. Proc. Rio Grande Val. Hort. Soc.**21**:74–79.

YOUNG, R. H., and E. O. OLSON. 1963. Freeze injury to citrus varieties in lower Rio Grande Valley of Texas. Proc. Amer. Soc. Hort. Sci. **83**:333–36.

YOUNG, R. H., and A. PEYNADO. 1961. Seasonal changes in the cold hardiness of ten-year-old redblush grapefruit trees as related to dormancy and temperature. Proc. Rio Grande Val. Hort. Soc. **15**:59–67.

——— 1962. Growth and cold hardiness of citrus and related species when exposed to different night temperatures. Proc. Amer. Soc. Hort. Sci. **81**:238–43.

——— 1965. Changes in cold hardiness and certain physiological factors of redblush grapefruit seedlings as affected by exposure to artificial hardening temperatures. Proc. Amer. Soc. Hort. Sci. **86**:244–52.

——— 1967*a*. Freezing and water-soaking in citrus leaves. Proc. Amer. Soc. Hort. Sci. **91**:157–62.

——— 1967*b*. Freeze injury to 3-year-old citrus hybrids and varieties following exposure to controlled freezing conditions. Proc. Rio Grande Val. Hort. Soc. **21**:80–88.

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APPENDIX I

SUPPLEMENTARY DATA ON LEAF ANALYSES*

* All citations for Appendix I will be found in the bibliography to Chapter 6, pp. 205 to 210.

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Table I–1
THE EFFECT OF ROOTSTOCK ON THE CON

Scion	Tree Age (Years)	Leaf Age (Months)	Position Leaf Sample	Culture	Special Treatment
Valencia orange	Not stated	Mature	Not stated	Field	None
Valencia orange	5	6	Nonfruiting shoot	Field	None
Mean of 2	Mature	5–6	Fruiting shoot	Field	None
Mean of 7	21	6	Not stated	Field	None
Eureka lemon	1	4	Nonfruiting shoot	Potted soil, glasshouse	Mean soil pH and N variables
Webb Redblush grapefruit	4	5	Not stated	Field	Mean salt & salinity variables
Mean of 2	7	3–6	Fruiting shoot	Field	None
Mean of 2	21	3–6	Fruiting shoot	Field	None
Redblush nucellar grapefruit	Mature	1	Nonfruiting shoot	Field	Micronutrient variable
Mean of 3 grapefruit	Mean, 6–8	6	Nonfruiting shoot	Field	None
Webb Redblush grapefruit	Mean, 6–8	6	Nonfruiting shoot	Field	Mean 3 cultural variables
Mean of 2	1	Not stated	Nonfruiting shoot	Nutrient solution	None
Satsuma orange	Not stated	4–8	Nonfruiting shoot	Potted soil	Mg variable
Mosambi sweet orange	5	3–5	Not stated	Field	None
Mean of 6	Mean, 4,6	3	Nonfruiting shoot	Field	None
Mean of 3	Not stated	Mature	Not stated	Field	None

* For details on the botany and nomenclature of rootstocks see Hodgson (1967), and Swingle and Reece (1967).

† Unpublished data of C. K. Labanauskas, W. P. Bitters, and J. D. Kirkpatrick, University of California, Riverside.

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CENTRATION OF ELEMENTS IN SCION LEAVES

Elemental Concentration Range	Relative Concentration Rank of Rootstocks[a]	Adapted From
	Nitrogen	
2.16–2.59%	Rubidoux sour orange < Savage citrange < trifoliate orange < African sour orange = Siamese shaddock = Cleopatra mandarin < Brazilian sour orange < Sampson tangelo < C.E.S 343 grapefruit = C.E.S. 362 sweet orange < rough lemon < Duncan grapefruit = lemon shaddock < Koethen sweet orange	Haas (1945*b*)
2.50–2.81%	Cleopatra mandarin < sour orange < Bowen grapefruit < Parson Brown (sweet) orange < rough lemon < Rusk citrange	Smith *et al.* (1949)
2.41–2.74%	Sampson tangelo < sour orange < grapefruit < sweet orange < rough lemon	Chapman and Brown (1950)
2.54–2.93%	Sour orange < trifoliate orange < Marsh grapefruit < sweet orange < rough lemon	Wallace, Naude *et al.* (1952)
1.65–3.03%	Trifoliate orange < rough lemon < sweet orange < grapefruit < sour orange	Wallace, North and Frolich (1953)
2.42, 2.43%	Cleopatra mandarin < sour orange	Cooper, Peynado, and Olson (1958)
2.54, 2.60%	Tangerina Cleopatra (Cleopatra mandarin) < laranja pera (sweet orange)	Gallo *et al.* (1960)
2.49–2.60%	Limao rugoso nacional (rough lemon) < Limao cravo (Rangpur lime) < laranja caipira (sweet orange)	Gallo, *et al.* (1960)
2.31, 2.40%	Sweet orange < rough lemon	Labanauskas (1962)
2.34, 2.36%	Cleopatra mandarin < sour orange	Leyden (1963)
2.16, 2.17%	Sour orange < Cleopatra mandarin	Leyden (1963)
3.00, 3.34%	Yuzu < trifoliate orange	Saito and Yamamoto (1963)
2.72, 2.87%	Trifoliate orange < Yuzu	Satō, Ishihara, and Hase (1963)
1.95–2.47%	Seville sour orange < Herale sour orange < Wheeny grapefruit < Bengal citron < Atalantia monophylla < Ada-jamir (*Citrus assamensis*) < billi kichili (Cleopatra mandarin) < Pani-jamir (sweet) lemon < Sohmyndong rough lemon < Mosambi sweet orange < Jamberi Bombay rough lemon < Jamberi kodur rough lemon < Karna Khatta < Rangpur lime	Gaafar (1967)
2.17–2.36%	Troyer citrange < Sampson tangelo < Cleopatra mandarin < Keen sour orange < Olivelands sweet orange < Stow grapefruit	Unpublished data Labanauskas, Bitters and Kirkpatrick†
	Phosphorus	
0.142, 0.153%	Sour orange < sweet orange	Haas (1945*b*)

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TABLE I–1—(CONTINUED)

Scion	Tree Age (Years)	Leaf Age (Months)	Position Leaf Sample	Culture	Special Treatment
Valencia orange	Not stated	Mature	Not stated	Field	None
Marsh grapefruit	Mature	Mature	Not stated	Field	None
Eureka lemon	Mature	Mature	Not stated	Field	None
Valencia orange	5	6	Nonfruiting shoot	Field	None
Mean of 2	Mature	5–6	Fruiting shoot	Field	None
Mean of 7	21	6	Not stated	Field	None
Eureka lemon	1	4	Nonfruiting shoot	Potted soil, glasshouse	Mean, soil pH and N variables
Mean of 2	7	3–6	Fruiting shoot	Field	None
Mean of 2	21	3–6	Fruiting shoot	Field	None
Mean of 3 grapefruit	Mean, 6–8	6	Nonfruiting shoot	Field	None
Webb Redblush grapefruit	Mean, 6–8	6	Nonfruiting shoot	Field	Mean 3 cultural variables
Mean of 2	1	Not stated	Nonfruiting shoot	Nutrient solution	None
Satsuma orange	Not stated	4–8	Nonfruiting shoot	Potted soil	Mg variable
Mosambi sweet orange	5	3–5	Not stated	Field	None
Mean of 6	Mean, 4,6	3	Nonfruiting shoot	Field	None
Mean of 3	Not stated	Mature	Not stated	Field	None

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Elemental Concentration Range	Relative Concentration Rank of Rootstocks	Adapted From
	(Phosphorus Continued)	
0.103–0.142%	Lemon shaddock < Rubidoux sour orange < Siamese shaddock = African sour orange < rough lemon < Cleopatra mandarin < C.E.S. 362 sweet orange < Brazilian sour orange = Savage citrange < Duncan grapefruit < Sampson tangelo = C.E.S. 343 grapefruit < trifoliate orange < Koethen sweet orange	Haas (1945*b*)
0.092–0.129%	Brazilian sour orange < lemon shaddock = trifoliate orange < Homosassa sweet orange < Camulos grapefruit < African sour orange = C.E.S. 362 sweet orange < rough lemon < Duncan grapefruit	Haas (1948)
0.073–0.119%	Brazilian sour orange < rough lemon < Rubidoux sour orange < Cleopatra mandarin < Madam Vinous sweet orange < sweet lemon < Bessie sweet orange < Duncan grapefruit < Koethen sweet orange < Sampson tangelo < C.E.S. 343 grapefruit	Haas (1948)
0.136–0.150%	Sour orange < Cleopatra mandarin < Bowen grapefruit = rough lemon < Rusk citrange < Parson Brown sweet orange	Smith *et al.* (1949)
0.108–0.117%	Sour orange < grapefruit < Sampson tangelo < sweet orange < rough lemon	Chapman and Brown (1950)
0.098–0.123%	Sour orange < rough lemon < sweet orange < Marsh grapefruit < trifoliate orange	Wallace, Naude *et al.* (1952)
0.054–0.082%	Sour orange < sweet orange < rough lemon < grapefruit < trifoliate orange	Wallace, North and Frolich (1953)
0.124–0.126%	Tangerina Cleopatra (Cleopatra mandarin) < laranja pera (sweet orange)	Gallo *et al.* (1960)
0.113–0.118%	Limao rugoso nacional (rough lemon) < limao cravo (Rangpur lime) < laranja caipira (sweet orange)	Gallo *et al.* (1960)
0.11, 0.12%	Cleopatra mandarin < sour orange	Leyden (1963)
0.10, 0.11%	Sour orange < Cleopatra mandarin	Leyden (1963)
0.14, 0.18%	Yuzu < trifoliate orange	Saito and Yamamoto (1963)
0.182, 0.192%	Yuzu < trifoliate orange	Satō *et al.* (1963)
0.126–0.148%	Seville sour orange < Herale sour orange < Bengal citron < Mosambi sweet orange < billi kichili (Cleopatra mandarin) < Wheeny grapefruit < Ada-jamir (*C. assamensis*) < Pani-jamir (sweet) lemon < Sohmyndong rough lemon < Karna Khatta < Jamberi kodur rough lemon < Jamberi Bombay rough lemon < *Atalantia monophylla* < Rangpur lime	Gaafar (1967)
0.175–0.203%	Keen sour orange < Cleopatra mandarin < Olivelands sweet orange < Troyer citrange < Sampson tangelo < Stow grapefruit	Unpublished data Labanauskas, Bitters and Kirkpatrick†
	Potassium	
0.94, 1.28%	Sour orange < sweet orange	Haas (1945*b*)

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TABLE I-1—(CONTINUED)

Scion	Tree Age (Years)	Leaf Age (Months)	Position Leaf Sample	Culture	Special Treatment
Valencia orange	Not stated	Mature	Not stated	Field	None
Marsh grapefruit	Mature	Mature	Not stated	Field	None
Eureka lemon	Mature	Mature	Not stated	Field	None
Valencia orange	5	6	Nonfruiting shoot	Field	None
Mean of 2	Mature	5–6	Fruiting shoot	Field	None
Shary Red grapefruit	1	4	Nonfruiting shoot	Field	No salt added
Shary Red grapefruit	1	4	Nonfruiting shoot	Field	Salt added
Mean of 2	1	6–12	Nonfruiting shoot	Field	Means salt + B variables
Mean of 7	21	6	Not stated	Field	None
Webb Red grapefruit	2	5	Nonfruiting	Field	Mean salt variables
Allen Eureka lemon	0.5	All leaves	Nonfruiting shoot	Soil in pots	Mean Na and K variables
Webb Redblush grapefruit	4	5	Not stated	Field	Mean salt and salinity variables
Mean of 2	7	3–6	Fruiting shoot	Field	None
Mean of 2	21	3–6	Fruiting shoot	Field	None
Mean of 3 grapefruit	Mean, 6–8	6	Nonfruiting shoot	Field	None
Webb Redblush grapefruit	Mean, 6–8	6	Nonfruiting	Field	Mean, 3
Mean of 2	1	Not stated	Nonfruiting shoot	Nutrient solution	None
Satsuma orange	Not stated	4–8	Nonfruiting shoot	Potted soil	Mg variable

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Elemental Concentration Range	Relative Concentration Rank of Rootstocks	Adapted From
	(Potassium Continued)	
0.58–0.92%	African sour orange < rough lemon < Rubidoux sour orange < Brazilian sour orange = Cleopatra mandarin < lemon shaddock < Siamese shaddock < Savage citrange < trifoliate orange = C.E.S. 362 sweet orange < C.E.S. 343 grapefruit < Koethen sweet orange < Duncan grapefruit < Sampson tangelo	Haas (1945*b*)
0.47–0.91%	Trifoliate orange < Brazilian sour orange < African sour orange < Homosassa sweet orange < C.E.S. 362 sweet orange < rough lemon < lemon shaddock < Camulos grapefruit < Duncan grapefruit	Haas (1948)
0.36–1.07%	Rough lemon < sweet lemon < Brazilian sour orange < Cleopatra mandarin < Rubidoux sour orange < Madam Vinous sweet orange < Bessie sweet orange < Koethen sweet orange < Sampson tangelo < C.E.S. 343 grapefruit < Duncan grapefruit	Haas (1948)
1.76–2.62%	Rusk citrange < Cleopatra mandarin < rough lemon < sour orange < Parson Brown (sweet) orange < Bowen grapefruit	Smith *et al.* (1949)
0.54–0.86%	Rough lemon < sour orange < sweet orange < grapefruit < Sampson tangelo	Chapman and Brown (1950)
1.60–2.81%	Cleopatra mandarin < Calamondin < sour orange < *Severinia buxifolia* = rough lemon < Rangpur lime < Rusk citrange < Minneola tangelo < Florida sweet orange < Sampson tangelo = Etrog citron < Cuban shaddock < Nakorn pummelo	Cooper and Gorton (1952)
1.33–2.85%	Cleopatra mandarin < Calamondin < Florida sweet orange < rough lemon = sour orange < Rangpur lime = *Severinia buxifolia* = Rusk citrange < Sampson tangelo < Minneola tangelo < Etrog citron < Cuban shaddock < Nakorn pummelo	Cooper and Gorton (1952)
2.16, 2.71%	Cleopatra mandarin < sour orange	Cooper, Gorton, and Olson (1952)
1.01–1.65%	Sour orange < rough lemon < trifoliate orange < sweet orange < Marsh grapefruit	Wallace, Naude, *et al.* (1952)
1.60, 2.04%	Cleopatra mandarin < sour orange	Gorton, Cooper, and Peynado (1954)
1.84–2.64%	Cleopatra mandarin < standard sour orange < Koethen sweet orange < Jochimsen grapefruit < Sampson tangelo < rough lemon < Rangpur lime	Jones, Martin, and Bitters (1957)
1.17, 1.52%	Cleopatra mandarin < sour orange	Cooper *et al.* (1958)
1.52, 1.82%	Tangerina Cleopatra (Cleopatra mandarin) < laranja pera (sweet orange)	Gallo *et al.* (1960)
1.29–1.44%	Limao cravo (Rangpur lime) < limao rugoso nacional (rough lemon) < laranja caipira (sweet orange)	Gallo *et al.* (1960)
0.77, 1.11%	Cleopatra mandarin < sour orange	Leyden (1963)
0.80, 0.85%	Cleopatra mandarin < sour orange	Leyden (1963)
2.57, 2.68%	Yuzu < trifoliate orange	Saito and Yamamoto (1963)
1.56, 1.85%	Trifoliate orange < Yuzu	Satō *et al.* (1963)

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TABLE I–1—(CONTINUED)

Scion	Tree Age (Years)	Leaf Age (Months)	Position Leaf Sample	Culture	Special Treatment
Mosambi sweet orange	5	3–5	Not stated	Field	None
Mean of 6	Mean, 4,6	3	Nonfruiting shoot	Field	None
Mean of 3	Not stated	Mature	Not stated	Field	None
Valencia orange	Not stated	Mature	Not stated	Field	None
Marsh grapefruit	Mature	Mature	Not stated	Field	None
Eureka lemon	Mature	Mature	Not stated	Field	None
Valencia orange	5	6	Nonfruiting shoot	Field	None
Mean of 2	Mature	5–6	Fruiting shoot	Field	None
Shary Red grapefruit	1	4	Nonfruiting shoot	Field	No salt added
Shary Red grapefruit	1	4	Nonfruiting shoot	Field	Salt added
Mean of 2	1	6-12	Nonfruiting shoot	Field	Mean salt and B variables
Mean of 7	21	6	Not stated	Field	None
Webb Red grapefruit	2	5	Nonfruiting shoot	Field	Mean salt variables
Allen Eureka lemon	0.5	All leaves	Nonfruiting shoot	Soil in pots	Mean Na and K variables
Webb Redblush grapefruit	4	5	Not stated	Field	Mean salt & salinity variables
Mean of 2	11 months	All leaves	Nonfruiting shoots	Flats in greenhouse	None
Mean of 2	7	3–6	Fruiting shoot	Field	None

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Elemental Concentration Range	Relative Concentration Rank of Rootstocks	Adapted From
	(Postassium Continued)	
0.77–1.06%	Herale sour orange < Bengal citron < Karna Khatta < Mosambi sweet orange < Sohmyndong rough lemon < Seville sour orange < billi kichili (Cleopatra mandarin) < Ada-jamir (*C. assamensis*) < Pani-jamir (sweet) lemon < Jamberi Bombay rough lemon = *Atalantia monophylla* < Jamberi kodur rough lemon < Wheeny grapefruit < Rangpur lime	Gaafar (1967)
1.07–1.43%	Cleopatra mandarin < Keen sour orange < Troyer citrange < Olivelands sweet orange < Stow grapefruit < Sampson tangelo	Unpublished data Labanauskas, Bitters, and Kirkpatrick†
	Calcium	
5.68, 6.34%	Sweet orange < sour orange	Haas (1945*b*)
4.94–6.50%	Koethen sweet orange < rough lemon < C.E.S. 362 sweet orange < Sampson tangelo < C.E.S. 343 grapefruit = lemon shaddock < African sour orange < Duncan grapefruit < Brazilian sour orange	Haas (1945*b*)
4.86–6.47%	Lemon shaddock < rough lemon < Camulos grapefruit < Homosassa sweet orange < Duncan grapefruit < C.E.S. 362 sweet orange < trifoliate orange < African sour orange < Brazilian sour orange	Haas (1948)
4.18–5.77%	Sweet lemon < rough lemon < Koethen sweet orange = C.E.S. 343 grapefruit < Rubidoux sour orange < Brazilian sour orange < Duncan grapefruit < Madam Vinous sweet orange < Sampson tangelo < Bessie sweet orange < Cleopatra mandarin	Haas (1948)
2.11–2.44%	Bowen grapefruit < Parson Brown (sweet) orange < sour orange < Cleopatra mandarin < Rusk citrange < rough lemon	Smith *et al.* (1949)
5.12–6.09%	Rough lemon < sweet orange < grapefruit < Sampson tangelo < sour orange	Chapman and Brown (1950)
1.68–3.19%	Nakorn pummelo < *Severinia buxifolia* < Rangpur lime < Cuban shaddock < Etrog citron < sour orange = Rusk citrange < Minneola tangelo < rough lemon < Florida sweet orange < Sampson tangelo < Cleopatra mandarin < Calamondin	Cooper and Gorton (1952)
2.38–4.23%	Cuban shaddock < Nakorn pummelo < Florida sweet orange < *Severinia buxifolia* = Etrog citron < sour orange = Rusk citrange < Rangpur lime = rough lemon < Minneola tangelo < Sampson tangelo < Calamondin < Cleopatra mandarin	Cooper and Gorton (1952)
3.62, 4.00%	Sour orange < Cleopatra mandarin	Cooper, Gorton, and Olson (1952)
3.68–4.79%	Rough lemon < Marsh grapefruit < sweet orange < trifoliate orange < sour orange	Wallace, Naude *et al.* (1952)
2.51, 2.95%	Sour orange < Cleopatra mandarin	Gorton *et al.* (1954)
2.75–3.59%	Sampson tangelo < Rangpur lime < Koethen sweet orange < Jochimsen grapefruit < standard sour orange < rough lemon < Cleopatra mandarin	Jones *et al.* (1957)
4.52, 4.89%	Cleopatra mandarin < sour orange	Cooper *et al.* (1958)
1.88, 1.26%	Trifoliate orange < rough lemon	Shannon & Zaphrir (1958)
3.39, 3.81%	Laranja pera (sweet orange) < tangerina Cleopatra (Cleopatra mandarin)	Gallo *et al.* (1960)

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TABLE I-1—(CONTINUED)

Scion	Tree Age (Years)	Leaf Age (Months)	Position Leaf Sample	Culture	Special Treatment
Mean of 2	21	3–6	Fruiting shoot	Field	None
Frost nucellar Eureka lemon	7	Youngest fully matured	Nonfruiting shoot	Field	None
Mean of 3 grapefruit	Mean, 6–8	6	Nonfruiting shoot	Field	None
Webb Redblush grapefruit	Mean, 6–8	6	Nonfruiting shoot	Field	Mean 3 cultural variables
Mean of 2	1	Not stated	Nonfruiting shoot	Nutrient solution	None
Satsuma orange	Not stated	4–8	Nonfruiting shoot	Potted soil	Mg variable
Mosambi sweet orange	5	3–5	Not stated	Field	None
Mean of 6	Mean, 4–6	3	Nonfruiting shoot	Field	None
Mean of 3	Not stated	Mature	Not stated	Field	None
Valencia orange	Not stated	Mature	Not stated	Field	None
Marsh grapefruit	Mature	Mature	Not stated	Field	None
Eureka lemon	Mature	Mature	Not stated	Field	None
Valencia orange	5	6	Nonfruiting shoot	Field	None
Mean of 2	Mature	5–6	Fruiting shoot	Field	None
Shary Red grapefruit	1	4	Nonfruiting shoot	Field	No salt added
Shary Red grapefruit	Mature	4	Nonfruiting shoot	Field	Salt added

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Elemental Concentration Range	Relative Concentration Rank of Rootstocks	Adapted From
	Calcium Continued)	
3.11–3.34%	Limao rugoso nacional (rough lemon) < limao cravo (Rangpur lime) < laranja caipira (sweet orange)	Gallo *et al.* (1960)
3.44–4.67%	Yuzu < Alemow < Gajanimma (*C. pennivesiculata*) < Rutherford sweet orange < Rangpur lime < Royal grapefruit < Nanshô-daidai	Embleton, Labanauskas and Bitters (1962)
5.08, 5.09%	Sour orange < Cleopatra mandarin	Leyden (1963)
5.37, 6.21%	Cleopatra mandarin < sour orange	Leyden (1963)
2.86, 3.24%	Trifoliate orange < Yuzu	Saito & Yamamoto (1963)
2.40, 2.48%	Yuzu < trifoliate orange	Satō *et al.* (1963)
4.16–4.99%	Bengal citron < Seville sour orange < Herale sour orange < Ada-jamir (*C. assamensis*) < Pani-jamir (sweet) lemon < Sohmyndong rough lemon < Jamberi kodur rough lemon < Jamberi Bombay rough lemon < Mosambi sweet orange < Wheeny grapefruit < Karna Khatta < billi kichili (Cleopatra mandarin) < *Atalantia monophylla* < Rangpur lime	Gaafar (1967)
2.53–2.81%	Olivelands sweet orange < Troyer citrange < Sampson tangelo < Stow grapefruit < Keen sour orange < Cleopatra mandarin	Unpublished data, Labanauskas, Bitters and Kirkpatrick†
	Magnesium	
0.42, 0.47%	Sweet orange < sour orange	Haas (1945*b*)
0.29–0.51%	Duncan grapefruit < C.E.S. 343 grapefruit < Koethen sweet orange < C.E.S. 362 sweet orange = Rubidoux sour orange < Brazilian sour orange < Sampson tangelo < African sour orange = Savage citrange < Cleopatra mandarin < rough lemon < trifoliate orange < Siamese shaddock < lemon shaddock	Haas (1945*b*)
0.35–0.50%	Duncan grapefruit < Camulos grapefruit < Brazilian sour orange < C.E.S. 362 sweet orange < African sour orange < Homosassa sweet orange = lemon shaddock < trifoliate orange < rough lemon	Haas (1948)
0.22–0.46%	Duncan grapefruit < Rubidoux sour orange < C.E.S. 343 grapefruit < Koethen sweet orange < Brazilian sour orange < Bessie sweet orange < Madam Vinous sweet orange < sweet lemon < Cleopatra mandarin < Sampson tangelo < rough lemon	Haas (1948)
0.37–0.51%	Bowen grapefruit < Parson Brown (sweet) orange < Cleopatra mandarin < sour orange < rough lemon < Rusk citrange	Smith *et al.* (1949)
0.36–0.48%	Grapefruit < sweet orange < sour orange = Sampson tangelo < rough lemon	Chapman and Brown (1950)
0.19–0.84%	Florida sweet orange < Cuban shaddock < Etrog citron < Cleopatra mandarin < Sampson tangelo < Nakorn pummelo < *Severinia buxifolia* < Rusk citrange < Rangpur lime < rough lemon < Minneola tangelo = sour orange = Calamondin	Cooper and Gorton (1952)
0.43–1.03%	Sampson tangelo < Cleopatra mandarin < Cuban shaddock < Rangpur lime < sour orange = Florida sweet orange < Rusk citrange < Nakorn pummelo = Etrog citron < Calamondin = *Severinia buxifolia* < Minneola tangelo < rough lemon	Cooper and Gorton (1952)

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TABLE I-1—(CONTINUED)

Scion	Tree Age (Years)	Leaf Age (Months)	Position Leaf Sample	Culture	Treatment Special
Mean of 7	21	6	Not stated	Field	None
Webb Red grapefruit	2	5	Nonfruiting shoot	Field	Mean salt variables
Allen Eureka lemon	0.5	All leaves	Nonfruiting shoot	Soil in pots	Mean Na and K variables
Webb Redblush grapefruit	4	5	Not stated	Field	Mean salt and salinity variables
Mean of 2	7	3–6	Fruiting shoot	Field	None
Mean of 2	21	3–6	Fruiting shoot	Field	None
Frost nucellar Eureka lemon	7	Youngest fully matured	Nonfruiting shoot	Field	None
Mean of 3 grapefruit	Mean, 6–8	6	Nonfruiting shoot	Field	None
Webb Redblush grapefruit	Mean, 6–8	6	Nonfruiting shoot	Field	Mean 3 cultural variables
Mean of 2	1	Not stated	Nonfruiting shoot	Nutrient solution	None
Satsuma orange	Not stated	4–8	Nonfruiting shoot	Potted soil	Mg variable
Mosambi sweet orange	5	3–5	Not stated	Field	None
Mean of 6	Mean, 4, 6	3	Nonfruiting shoot	Field	None
Valencia orange	Not stated	Mature	Not stated	Field	None
Webb Red grapefruit	2	5	Nonfruiting shoot	Field	Mean salt variables
Webb Redblush grapefruit	4	5	Not stated	Field	Mean salt and salinity variables
Mean of 2	Mature	Mature	Nonfruiting shoot	Field	None
Eureka lemon	3	Mature	Nonfruiting shoot	Sand	4 ppm B nutrient solution

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Elemental Concentration Range	Relative Concentration Rank of Rootstocks	Adapted From
	Magnesium Continued)	
0.11–0.20%	Marsh grapefruit < sour orange < sweet orange < trifoliate orange < rough lemon	Wallace, Naude *et al.* (1952)
0.72, 0.84%	Sour orange < Cleopatra mandarin	Gorton *et al.* (1954)
0.20–0.27%	Rangpur lime < Koethen sweet orange = standard sour orange = Jochimsen grapefruit = rough lemon < Sampson tangelo < Cleopatra mandarin	Jones *et al.* (1957)
0.29, 0.42%	Sour orange < Cleopatra mandarin	Cooper *et al.* (1958)
0.29, 0.35%	Laranja pera (sweet orange) < tangerina Cleopatra (Cleopatra mandarin)	Gallo *et al.* (1960)
0.26–0.30%	Limao rugoso nacional (rough lemon) < laranja caipira (sweet orange) < limao cravo (Rangpur lime)	Gallo *et al.* (1960)
0.34–0.47%	Alemow < Gajanimma (*C. pennivesiculata*) < Royal grapefruit < Rangpur lime = Rutherford sweet orange < Yuzu < Nanshō-daidai	Embleton Labanauskas and Bitters (1962)
0.41, 0.56%	Sour orange < Cleopatra mandarin	Leyden (1963)
0.34, 0.54%	Sour orange < Cleopatra mandarin	Leyden (1963)
0.34, 0.48%	Yuzu < trifoliate orange	Saito & Yamamoto (1963)
0.26, 0.31%	Yuzu < trifoliate orange	Satō *et al.* (1963)
0.31–0.38%	Bengal citron < Herale sour orange < Pani-jamir (sweet) lemon < Karna Khatta < Ada-jamir (*C. assamensis*) < billi kichili (Cleopatra mandarin) < Seville sour orange < *Atlantia monophylla* < Rangpur lime < Wheeny grapefruit < Sohmyndong rough lemon < Jamberi kodur rough lemon < Mosambi sweet orange < Jamberi Bombay rough lemon	Gaafar (1967)
0.24–0.32%	Stow grapefruit < Olivelands sweet orange < Keen sour orange < Sampson tangelo < Cleopatra mandarin < Troyer citrange	Unpublished data Labanauskas, Bitters, and Kirkpatrick†
	Sulfur	
0.23–0.32%	Cleopatra mandarin = trifoliate orange < Brazilian sour orange = Rubidoux sour orange = Sampson tangelo = Lemon shaddock < African sour orange = Koethen sweet orange = C.E.S. 362 sweet orange < Siamese shaddock < C.E.S. 343 grapefruit = Savage citrange < Duncan grapefruit < rough lemon	Haas (1945b)
0.32, 0.37%	Sour orange < Cleopatra mandarin	Gorton *et al.* (1954)
0.25, 0.31%	Sour orange < Cleopatra mandarin	Cooper *et al.* (1958)
0.42–1.02%	Rough lemon < Cleopatra mandarin < Rusk citrange < sweet orange < sour orange < Bowen grapefruit	Rasmussen & Smith (1958)
	Boron	
83, 1065 ppm	*Severinia buxifolia* < Eureka lemon	Eaton and Blair (1935)

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TABLE I–1—(CONTINUED)

Scion	Tree Age (Years)	Leaf Age (Months)	Position Leaf Sample	Culture	Special Treatment
Valencia orange	Not stated	Not stated	Not stated	Nursery	None
Duncan grapefruit	Not stated	Not stated	Not stated	Nursery	None
Temple orange	Not stated	Not stated	Not stated	Nursery	None
Dancy tangerine	Not stated	Not stated	Not stated	Nursery	None
Mean of 7	4	Not stated	Not stated	Field	None
Parson Brown orange	Not stated	Not stated	Not stated	Nursery	None
Valencia orange	Not stated	Mature	Not stated	Field	None
Valencia orange	Not stated	Mature	Not stated	Field	None
Eureka lemon	Not stated	Mature	Not stated	Field	None
Mean of 2	Not stated	Mature	Not stated	Field	None
Valencia orange	5	6	Nonfruiting shoot	Field	None
Mean of 2	1	6–12	Nonfruiting shoot	Field	Mean salt and B variables
Shary Red grapefruit	Young	7	Nonfruiting shoot	Field	B exp.
Shary Red grapefruit	Young	9	Nonfruiting shoot	Field	B exp.
Shary Red grapefruit	Young	3	Nonfruiting shoot	Field	B exp.
Shary Red grapefruit	Young	7	Nonfruiting shoot	Field	B exp.
Shary Red grapefruit	2	5	Nonfruiting shoot	Field	0.5 ppm B in irrigation water
Shary Red grapefruit					

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Elemental Concentration Range	Relative Concentration Rank of Rootstocks	Adapted From
	(Boron Continued)	
19–68 ppm	Sour orange No. 1 < sour orange No. 2 < sour orange No. 3 < Calamondin < Parson Brown (sweet) orange < Bowen grapefruit < trifoliate orange = Cleopatra mandarin < rough lemon < Rusk citrange < Cuban shaddock	Roy (1943)
24–71 ppm	Bittersweet sour orange < Calamondin < sour orange No. 2 < Duncan grapefruit < Rusk citrange < Kansu (Yuzu) orange = Sunkat (Sunki) mandarin < sweet lemon < trifoliate orange < Cuban shaddock	Roy (1943)
26-80 ppm	Bittersweet sour orange < Calamondin < sour orange No. 2 < Morton citrange < Pineapple (sweet) orange < Sunkat (Sunki) mandarin < Kansu (Yuzu) Orange < Duncan grapefruit < sweet lemon < trifoliate orange < Cuban shaddock	Roy (1943)
30–73 ppm	Calamondin = Bittersweet sour orange < Pineapple (sweet) orange < Duncan grapefruit < Cuban shaddock < Sunkat (Sunki) mandarin < trifoliate orange = sweet lemon	Roy (1943)
34–68 ppm	Sour orange < Valencia (sweet) orange < Cleopatra mandarin < rough lemon < grapefruit	Roy (1943)
14–74 ppm	Sour orange No. 1 < sour orange No. 2 < sour orange No. 3 = Bittersweet sour orange < sour orange A < Calamondin < sweet lemon < Cleopatra mandarin < Parson Brown (sweet) orange < Kansu (Yuzu) orange < Sunkat (Sunki) mandarin < Pineapple (sweet) orange < rough lemon < Duncan grapefruit = Rusk citrange < Bowen grapefruit < trifoliate orange < Cuban shaddock	Roy (1943)
43–120 ppm	Brazilian sour orange = African sour orange < Rubidoux sour orange < C.E.S. 343 grapefruit < Koethen sweet orange < C.E.S. 362 sweet orange < Siamese shaddock < Duncan grapefruit < Sampson tangelo < Savage citrange = rough lemon < Cleopatra mandarin < lemon shaddock < trifoliate orange	Haas (1945*a*)
83–149 ppm	Sour orange < pomelo (grapefruit) < sweet orange < trifoliate orange	Haas (1945*a*)
67–99 ppm	Sour orange < pomelo (grapefruit) < sweet orange	Haas (1945*a*)
48, 85 ppm	Sour orange < sweet orange	Haas (1945*a*)
67–95 ppm	Sour orange < rough lemon < Cleopatra mandarin < Parson Brown (sweet) orange < Bowen grapefruit < Rusk citrange	Smith *et al.* (1949)
396, 534 ppm	Sour orange < Cleopatra mandarin	Cooper, Gorton, and Olson (1952)
382, 449 ppm	Sour orange < Cleopatra mandarin	Cooper, Peynado and Shull (1955)
315, 358 ppm	Sour orange < Cleopatra mandarin	Cooper, Peynado and Shull (1955)
299, 302 ppm	Cleopatra mandarin < sour orange	Cooper, Peynado and Shull (1955)
405, 484 ppm	Sour orange < Cleopatra mandarin	Cooper, Peynado and Shull (1955)
105–305 ppm	Duncan grapefruit < Rusk citrange < sour orange < rough lemon = sweet lemon < *Severinia buxifolia* < Etrog citron < Calamondin < trifoliate orange < Rangpur lime < Nakorn pummelo < C.P.B. 4475 citrumelo = Pineapple (sweet) orange < Florida sweet orange = Williams tangelo < Sampson tangelo < Minneola tangelo < Cleopatra mandarin < Columbian sweet lime	Cooper, Peynado and Shull (1955)

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TABLE I–1—(CONTINUED)

Scion	Tree Age (Years)	Leaf Age (Months)	Position Leaf Sample	Culture	Special Treatment
Shary Red grapefruit	2	5	Nonfruiting shoot	Field	6.0 ppm B in irrigation water
Shary Red grapefruit	4	Not stated	Nonfruiting shoot	Field	High-B irrigation water
Shary Red grapefruit	5	Not stated	Nonfruiting shoot	Field	High-B irrigation water
Valencia orange	5	Not stated	Nonfruiting shoot	Field	High-B irrigation water
Webb Redblush grapefruit	4	5	Not stated	Field	Mean salt and salinity variables
Nucellar Redblush grapefruit	1	Not stated	Nonfruiting shoot	Field	High-salt irrigation water
Frost nucellar Eureka lemon	7	Youngest fully matured	Nonfruiting shoot	Field	None
Frost nucellar Eureka lemon	Mature	Youngest fully matured	Nonfruiting shoot	Field	None
Lisbon lemon	Mature	Youngest fully matured	Nonfruiting shoot	Field	None
Nucellar Redblush grapefruit	3	Not stated	Nonfruiting shoot	Field	High-salt irrigation water
Mosambi sweet orange	5	3-5	Not stated	Field	None
Redblush nucellar grapefruit	Mature	1	Nonfruiting shoot	Field	Micro-nutrient variables

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Elemental Concentration Range	Relative Concentration Rank of Rootstocks	Adapted From
	Boron Continued	
310–880 ppm	Rough lemon ⟨*Severinia buxifolia* ⟨ Duncan grapefruit ⟨ Minneola tangelo ⟨ Pineapple (sweet) orange ⟨ Rusk citrange ⟨ trifoliate orange ⟨ Cleopatra mandarin ⟨ sour orange ⟨ Etrog citron ⟨ Rangpur lime ⟨ Calamondin ⟨ C.P.B. 4475 citrumelo ⟨ sweet lemon ⟨ Florida sweet orange ⟨ Nakorn pummelo ⟨ Sampson tangelo ⟨ Columbian sweet lime	Cooper, Peynado and Shull (1955)
149–425 ppm	Homosassa (sweet) orange ⟨ Uvalde citrange ⟨ Pineapple (sweet) orange ⟨ Calashu ⟨ Troyer citrange ⟨Rustic citrange ⟨ Webb Redblush grapefruit ⟨ Cleopatra mandarin ⟨ C.P.B. 4475 citrumelo ⟨ Sanders citrange ⟨ Ponkan mandarin ⟨ Sampson tangelo = Rusk citrange ⟨ Savage citrange ⟨ Duncan grapefruit ⟨ Rose (Rangpur) lime ⟨ lemonquat ⟨ Sunkat (Sunki) mandarin = rough lemon ⟨ C.P.B. 43301-A2 citrangor ⟨ sour orange ⟨ Lau Chang mandarin ⟨ P.I. 117477 mandarin ⟨ Thomasville citrangequat ⟨ Dancy mandarin ⟨ Williams tangelo ⟨ Cuban shaddock ⟨ Butnal sweet lime ⟨ Clementine mandarin ⟨ Palestine sweet lime ⟨ Columbian sweet lime	Cooper, Peynado and Shull (1955)
64–519 ppm	*Severinia buxifolia* ⟨ Pineapple (sweet) orange ⟨ Homosassa (sweet) orange ⟨ Sunshine tangelo ⟨ sour orange ⟨ Webber tangelo ⟨ Rangpur lime ⟨ rough lemon ⟨ Pina tangelo ⟨ Columbian sweet lime ⟨ Cleopatra mandarin ⟨ Thornton tangelo ⟨ Watt tangelo ⟨ sweet lemon	Cooper, Peynado and Shull (1955)
61–518 ppm	*Severinia buxifolia* ⟨ sour orange ⟨ pineapple (sweet) orange ⟨ Pina tangelo ⟨ Thornton tangelo ⟨ Watt tangelo ⟨ sweet lemon	Cooper *et al.* (1955)
783, 821 ppm	Sour orange ⟨ Cleopatra mandarin	Cooper *et al.* (1958)
282–1174 ppm	Alemow ⟨ Gajanimma ⟨ Carrizo citrange ⟨ Columbian sweet lime ⟨ sour orange ⟨ Sunki mandarin ⟨ Rangpur lime ⟨ Troyer citrange ⟨ Timkat mandarin ⟨ Citrumelo 4475 ⟨ Savage citrange ⟨ Cleopatra mandarin ⟨ Ponkan mandarin	Cooper and Peynado (1959)
101–218 ppm	Alemow ⟨ Gajanimma (*C. pennivesiculata*) ⟨Rangpur lime ⟨ Rutheford sweet orange ⟨ Nanshô-daidai ⟨ Yuzu ⟨ Royal grapefruit	Embleton *et al.* (1962)
88–156 ppm	Alemow ⟨ Oklawaha sour orange ⟨ Sauvage sour orange	Embleton *et al.* (1962)
28, 45 ppm	Alemow ⟨ sour orange	Embleton *et al.* (1962)
278–1300 ppm	Alemow ⟨ Gajanimma ⟨ sour orange ⟨ Columbian sweet lime ⟨ Rangpur lime ⟨ Carrizo citrange ⟨ Savage citrange ⟨ Cleopatra mandarin ⟨ Troyer citrange ⟨ Sunki mandarin ⟨ Timkat mandarin ⟨ Ponkan mandarin ⟨ Citrumelo 4475	Peynado & Young (1962)
69–87 ppm	Herale sour orange ⟨ Wheeny grapefruit ⟨ billi kichili (Cleopatra mandarin) ⟨ Seville sour orange ⟨ Pani-jamir (sweet) lemon ⟨ *Atalantia monophylla* ⟨ Mosambi sweet orange ⟨ Bengal citron ⟨ Jamberi kodur rough lemon ⟨ Karna Khatta ⟨ Sohmyndong rough lemon ⟨ Jamberi Bombay rough lemon ⟨ Rangpur lime ⟨ Ada-jamir (*C. assamensis*)	Gaafar (1967)
49 ppm	Rough lemon = sweet orange	Labanauskas (1962)

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TABLE I–1—(CONTINUED)

Scion	Tree (Years) Age	Tree Age (Months)	Position Leaf Sample	Culture	Special Treatment
Mean of 6	Mean, 4,6	3	Nonfruiting shoot	Field	None
Valencia orange	5	6	Nonfruiting shoot	Field	None
Eureka lemon	1	4	Nonfruiting shoot	Potted soil, glass house	Soil pH 5.0, mean N rates Soil pH 6.4, mean N rates Soil pH 7.5, mean N rates
Frost nucellar Eureka lemon	7	Youngest fully matured	Nonfruiting shoot	Field	None
Redblush nucellar grapefruit	Mature	1	Nonfruiting shoot	Field	Micro-nutrient variables
Mean of 2	1	4	Nonfruiting shoot	Nutrient solution	Fe variable
Mean of 2	1	Fully expanded	Nonfruiting shoot	Potted soil, glass-house	Acid soil Alkaline soil
Mean of 6	Mean, 4,6	3	Nonfruiting shoot	Field	None
Valencia orange	5	6	Nonfruiting shoot	Field	None
Frost nucellar Eureka lemon	7	Youngest fully matured	Nonfruiting shoot	Field	None
Redblush nucellar grapefruit	Mature	1	Nonfruiting shoot	Field	Micro-nutrient variables
Mosambi sweet orange	5	3–5	Not stated	Field	None
Mean of 6	Mean, 4,6	3	Nonfruiting shoot	Field	None

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Elemental Concentration Range	Relative Concentration Rank of Rootstocks	Adapted From
70–79 ppm	Keen sour orange = Olivelands sweet orange < Cleopatra mandarin < Troyer citrange < Stow grapefruit < Sampson tangelo	Unpublished data Labanauskas, Bitters and Kirkpatrick†
	Iron	
59–130 ppm	Bowen grapefruit < sour orange < Parson Brown (sweet) orange < Cleopatra mandarin < rough lemon < Rusk citrange	Smith *et al.* (1949)
58–197 ppm	Trifoliate orange < grapefruit < sweet orange < rough lemon < sour orange	Wallace *et al.* (1953)
63–113 ppm	Grapefruit < sweet orange < trifoliate orange < sour orange < rough lemon	
51–103 ppm	Sour orange < trifoliate orange < rough lemon < grapefruit < sweet orange	
103–221 ppm	Rangpur lime < Nanshô-daidai < Gajanimma (*C. penniversiculata*) < Rutherford sweet orange < Alemow < Royal grapefruit < Yuzu	Embleton, Labanauskas and Bitters (1962)
33, 39 ppm	Sweet orange < rough lemon	Labanauskas (1962)
38 ppm	Koethen sweet orange = standard sour orange	Wallihan and Garber (1968*a*)
68, 143 ppm	Standard sour orange < Koethen sweet orange	Wallihan and Garber (1968*b*)
34, 37 ppm	Koethen sweet orange < standard sour orange	
58, 78 ppm	Sampson tangelo < Olivelands sweet orange < Cleopatra mandarin < Keen sour orange < Stow grapefruit < Troyer citrange	Unpublished data Labanauskas, Bitters, and Kirkpatrick†
	Magnanese	
53–88 ppm	Parson Brown (sweet) orange < Bowen grapefruit < sour orange < Rusk citrange < rough lemon < Cleopatra mandarin	Smith *et al.* (1949)
31–56 ppm	Rutherford sweet orange < Royal grapefruit < Gajanimma (*C. pennivesiculata*) < Nanshô-daidai < Rangpur lime < Alemow < Yuzu	Embleton, Labanauskas, and Bitters (1962)
12, 17 ppm	Sweet orange < rough lemon	Labanauskas (1962)
31–53 ppm	Seville sour orange < billi kichili (Cleopatra mandarin) < Herale sour orange < Jamberi Bombay rough lemon < Bengal citron = Ada-jamir (*C. assamensis*) < Wheeny grapefruit < Mosambi sweet orange < Karna Khatta < Pani-jamir (sweet) lemon < Sohmyndong rough lemon < Jamberi kodur rough lemon < Rangpur lime <*Atalantia monophylla*	Gaafar (1967)
14–17 ppm	Olivelands sweet orange = Sampson tangelo < Troyer citrange < Cleopatra mandarin = Stow grapefruit = Keen sour orange	Unpublished data Labanauskas, Bitters, and Kirkpatrick†

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TABLE I–1—(CONTINUED)

Scion	Tree Age (Years)	Leaf Age (Months)	Position Leaf Sample	Culture	Special Treatment
Valencia orange	5	6	Nonfruiting shoot	Field	None
Redblush nucellar grapefruit	Mature	1	Nonfruiting shoot	Field	Micro-nutrient variables
Mosambi sweet orange	5	3–5	Not stated	Field	None
Mean of 6	Mean, 4,6	3	Nonfruiting shoot	Field	None
Valencia orange	5	6	Nonfruiting shoot	Field	None
Redblush nucellar grapefruit	Mature	1	Nonfruiting shoot	Field	Micro-nutrient variables
Mosambi sweet orange	5	3–5	Not stated	Field	None
Mean of 6	Mean, 4,6	3	Nonfruiting shoot	Field	None
Shary Red grapefruit	1.5	5 and 7	Nonfruiting shoot	Field	High salt
Shary Red grapefruit	1.5	5 and 7	Nonfruiting shoot	Field	High salt
Shary Red grapefruit	1.5	5 and 7	Nonfruiting shoot	Field	High salt
Shary Red grapefruit	1.5	5 and 7	Nonfruiting shoot	Field	High salt
Shary Red grapefruit	1.5	5 and 7	Nonfruiting shoot	Field	High salt
Shary Red grapefruit	1	4	Nonfruiting shoot	Field	No salt added

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Elemental Concentration Range	Relative Concentration Rank of Rootstocks	Adapted From
	Zinc	
17–34 ppm	Sour orange < Parson Brown (sweet) orange < Rusk citrange < rough lemon < Bowen grapefruit < Cleopatra mandarin	Smith *et al.* (1949)
22, 23 ppm	Rough lemon < sweet orange	Labanauskas (1962)
34–40 ppm	Herale sour orange < Seville sour orange < Wheeny grapefruit < Ada-jamir (*C. assamensis*) < Sohmyndong rough lemon < *Atalantia monophylla* < billi kichili (Cleopatra mandarin) < Jamberi kodur rough lemon < Karna Khatta < Mosambi sweet orange < Pani-jamir (sweet lemon < Bengal Citron < Jamberi Bombay rough lemon < Rangpur lime	Gaafar (1967)
16–20 ppm	Troyer citrange < Cleopatra mandarin < Olivelands sweet orange = Keen sour orange = Stow grapefruit < Sampson tangelo	Unpublished data Labanauskas, Bitters, and Kirkpatrick†
	Copper	
5.0–8.3 ppm	Sour orange < Cleopatra mandarin < rough lemon < Bowen grapefruit < Parson Brown (sweet) orange < Rusk citrange	Smith *et al.* (1949)
6.5, 7.1 ppm	Rough lemon < sweet orange	Labanauskas (1962)
14.8–19.3 ppm	Seville sour orange < Rangpur lime < Ada-jamir (*C. assamensis*) billi kichili (Cleopatra mandarin) < Herale sour orange < Pani-jamir (sweet) lemon < Wheeny grapefruit < Bengal citron < *Atalantia monophylla* < Jamberi kodur rough lemon < Mosambi sweet orange < Jamberi Bombay rough lemon < Karna Khatta < Sohmyndong rough lemon	Gaafar (1967)
6.3–8.3 ppm	Troyer citrange < Stow grapefruit < Cleopatra mandarin < Sampson tangelo = Keen sour orange < Olivelands sweet orange	Unpublished data Labanauskas, Bitters, and Kirkpatrick†
	Chlorine	
1.4–2.5%	Williams tangelo < Minneloa tangelo < Sampson tangelo < sour orange < Florida sweet orange	Cooper, Gorton, and Edwards (1951)
1.7–2.5%	Duncan grapefruit < Nakorn pummelo < Cuban shaddock < Pineapple (sweet) orange < sour orange	Cooper, Gorton, and Edwards (1951)
0.4–2.6%	Rangpur lime < rough lemon < sweet lemon < sour orange < Columbian sweet lime	Cooper, Gorton, and Edwards (1951)
0.7–2.9%	Cleopatra mandarin < *C. nobilis* < sour orange < Calamondin < Rusk citrange	Cooper, Gorton, and Edwards (1951)
0.6–3.5%	*Severinia buxifolia* < sour orange < Citrumelo 4475 < trifoliate orange < citron	Cooper, Gorton, and Edwards (1951)
0.10–0.89%	Rangpur lime < Cleopatra mandarin < Sampson tangelo < rough lemon < Minneola tangelo < Nakorn pummelo = *Severinia buxifolia* < sour orange < Calamondin < Cuban shaddock < Florida sweet orange = Rusk citrange < Etrog citron	Cooper and Gorton (1952)

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TABLE I–1—(CONTINUED)

Scion	Tree Age (Years)	Leaf Age (Months)	Position Leaf Sample	Culture	Special Treatment
Shary Red grapefruit	1	4	Nonfruiting shoot	Field	Salt added
Mean of 2	1	6–12	Nonfruiting shoot	Field	Mean salt and B variables
Mean of 3	1	Not stated	Nonfruiting shoot	Field	High-salt irrigation water
Shary Red grapefruit	1	Not stated	Nonfruiting shoot	Field	High-salt irrigation water
Shary Red grapefruit	2	4	Nonfruiting shoot	Field	Rio Grande irrigation water
Shary Red grapefruit	2	4	Nonfruiting shoot	Field	Rio Grande irrigation water
Webb Red grapefruit	2	5	Nonfruiting shoot	Field	Mean salt variables
Webb Redblush grapefruit	4	5	Not stated	Field	Mean salt & salinity variables
Young-line Redblush grapefruit	1	Not stated	Nonfruiting shoot	Field	High-salt irrigation water
Ruby Red grapefruit	2	4	Nonfruiting shoot	Field	Rio Grande irrigation water

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Elemental Concentration Range	Relative Concentration Rank of Rootstocks	Adapted From
	(Chlorine Continued)	
0.43–3.51%	Rangpur lime < *Severinia buxifolia* < Cleopatra mandarin < rough lemon < Minneola tangelo < Sampson tangelo < sour orange = Nakorn pummelo < Calamondin < Cuban shaddock < Florida sweet orange < Rusk citrange < Etrog citron	Cooper and Gorton (1952)
0.58, 1.11%	Cleopatra mandarin < sour orange	Cooper, Gorton, and Olson (1952)
0.90, 2.40%	Cleopatra mandarin < sour orange	Cooper, Cowley and Shull (1952)
0.90–1.20%	Rangpur lime < Kusaie (Rangpur) lime = Poak Ling Ming (Rangpur) lime < Cleopatra mandarin	Cooper, Cowley and Shull (1952)
0.24–0.89%	Lau Chang mandarin < Changsha mandarin < Webb grapefruit < Oneco (Ponkan) mandarin < Dancy tangerine = Sampson tangelo < Choo Chou Tien Chieh mandarin < Suenkat (Sunki) mandarin < Cleopatra mandarin < Sanguinea mandarin = Rangpur lime < sour orange < Calashu mandarin < Pong Koa mandarin < rough lemon < P.I. 117477 mandarin < Ponkan mandarin < Gzel (sweet) orange < Calamondin < Pineapple (sweet) orange < Clementine mandarin < Avena Blood (sweet) orange < Louisiana (sweet) orange < Cadena Panchose (sweet) orange < Hamlin (sweet) orange < Weldon (sweet) orange < Citrumelo 4475 < Precoce (sweet) orange < Highgrove citremon < Savage citrange < Rustic citrange < Rusk citrange < Brownell citradia < Uvaldi citrange < Citrangor 43301-A2 < Saunders citrange < Thomasville citrangequat < Troyer citrange	Cooper and Shull (1953)
.20–0.46%	Sunki mandarin < Webber tangelo < Kinnow mandarin < Thornton tangelo < Duncan grapefruit < Williams tangelo = San Jacinto tangelo < Bergaldin 50359 < Altoona tangelo < King mandarin < Cuban shaddock < Palestine sweet lime < African pummelo < Kara mandarin	Cooper and Shull (1953)
23, 0.80%	Cleopatra mandarin < sour orange	Gorton *et al.* (1954)
22, 0.35%	Cleopatra mandarin < sour orange	Cooper *et al.* (1958)
10–2.43%	Sunki mandarin < Timkat mandarin < Cleopatra mandarin < Rangpur lime < sour orange < Ponkan mandarin < Alemow < Columbian sweet lime < Citrumelo 4475 < Savage citrange < Gajanimma < Carrizo citrange < Troyer citrange	Cooper and Peynado (1959)
02–1.01%	Sunki mandarin < Ponkan mandarin < Dancy tangerine < Cleopatra mandarin = Rangpur lime < Sampson tangelo < Oneco (Ponkan) mandarin < P.I. 117477 mandarin < Calsha mandarin = Lau Chang mandarin = rough lemon < Changsha mandarin = sour orange = Sanguinea mandarin < Pong Koa mandarin < Suenkat (Sunki) mandarin < Kinnow mandarin < King mandarin < Choo Chou Tien Chieh mandarin < Gzel (sweet) orange < Pineapple (sweet) orange < Brownell citradia < Clementine mandarin = Citrumelo 4475 < Avena blood (sweet) orange < Calamondin = Precoce de Valence (sweet) orange = Louisiana (sweet) orange < Ruby Red grapefruit < Highgrove citremon < Hamlin (sweet) orange < Cunningham citrange < Kara mandarin < Rusk citrange = Cuban shaddock < Palestine sweet lime < Rustic citrange < Savage citrange < Uvaldi citrange < Saunders citrange < Citrangor 43301-A2 < Troyer citrange < Thomasville citrangequat	Cooper (1961)

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TABLE I–1—(CONTINUED)

Scion	Tree Age (Years)	Leaf Age (Months)	Position Leaf Sample	Culture	Special Treatment
Young-line Redblush grapefruit	3	Not stated	Nonfruiting shoot	Field	High-salt irrigation water
Washington navel orange	Young	Mature	Not stated	Glasshouse	High-NaCl irrigation water
Valencia orange	Young	5	Not stated	Pot	Mean salt variables
Mean of 6	Mean, 4,6	3	Nonfruiting shoot	Field	None
Valencia orange	5	6	Nonfruiting shoot	Field	None
Shary Red grapefruit	1	4	Nonfruiting shoot	Field	No salt added
Shary Red grapefruit	1	4	Nonfruiting shoot	Field	Salt added
Mean of 2	1	6–12	Nonfruiting shoot	Field	Mean salt and B variables
Mean of 3	1	Not stated	Nonfruiting shoot	Field	High-salt irrigation water
Shary Red grapefruit	1	Not stated	Nonfruiting shoot	Field	High-salt irrigation water
Shary Red grapefruit	2	4	Nonfruiting shoot	Field	Rio Grande irrigation water
Shary Red grapefruit	2	4	Nonfruiting shoot	Field	Rio Grande irrigation water
Allen Eureka lemon	0.5	All leaves	Nonfruiting shoot	Soil in pots	Mean Na and K variables

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Elemental Concentration Range	Relative Concentration Rank of Rootstocks	Adapted From
	(Chlorine Continued)	
0.24–2.14%	Sunki mandarin < Cleopatra mandarin < Timkat mandarin < Rangpur lime < Ponkan mandarin < Citrumelo 4475 < sour orange < Columbian sweet lime < Alemow < Savage citrange < Troyer citrange < Carrizo citrange < Gajanimma	Peynado and Young (1962)
0.2, 0.8%	Citronelle (rough lemon) < trifoliata (trifoliate orange)	Smith 1963)
0.19, 0.56%	Rough lemon < trifoliate orange	Cradock and Weir (1964)
0.052–0.057%	Keen sour orange < Troyer citrange < Stow grapefruit = Olivelands sweet orange < Sampson tangelo < Cleopatra mandarin	Unpublished data Labanauskas, Bitters and Kirkpatrick†
	Soduim	
0.048–0.053%	Sour orange < Cleopatra mandarin < rough lemon < Bowen grapefruit < Parson Brown, (sweet) orange < Rusk citrange	Smith *et al.* (1949)
0.04–0.18%	Cleopatra mandarin = sour orange = Nakorn pummelo = Florida sweet orange = Cuban shaddock = Rusk citrange < rough lemon < *Severinia buxifolia* < Rangpur lime < Sampson tangelo = Calamondin < Mineola tangelo < Etrog citron	Cooper and Gorton (1952)
0.04–0.32%	Nakorn pummelo < *Severinia buxifolia* < Rangpur lime = rough lemon = sour orange = Rusk citrange < Florida sweet orange < Cuban shaddock < Sampson tangelo < Cleopatra mandarin = Minneola tangelo < Etrog citron < Calamondin	Cooper and Gorton (1952)
0.119, 0.144%	Sour orange < Cleopatra mandarin	Cooper, Gorton, and Olson (1952)
0.25, 0.35%	Sour orange < Cleopatra mandarin	Cooper, Cowley and Shull (1952)
0.34–0.48%	Poak Ling Ming (Rangpur) lime < Kusaie (Rangpur) lime < Rangpur lime < Cleopatra mandarin	Cooper, Cowley and Shull (1952)
0.21–0.41%	Citrangor 43301-A2 < Rusk citrange < sour orange < Pineapple (sweet) orange < Gzel (sweet) orange < Cleopatra mandarin = Changsha mandarin = Savage citrange < rough lemon < Highgrove citremon < Weldon (sweet) orange < Hamlin (sweet) orange = Cadena Panchose (sweet) orange < Citrumelo 4475 < Sanguinea mandarin < Precoce de Valence (sweet) orange < Uvaldi citrange < P.I. 117477 mandarin < Clementine mandarin = Troyer citrange = Rangpur lime = Avena Blood (sweet) orange < Louisiana (sweet) orange = Rustic citrange < Webb grapefruit < Dancy tangerine < Lau Chang mandarin < Sampson tangelo < Ponkan mandarin < Pong Koa mandarin < Calamondin = Calashu mandarin < Thomasville citrangequat < Suenkat (Sunki) mandarin < Choo Chou Tien Chieh mandarin < Oneco (Ponkan) mandarin < Brownell citradia < Saunders citrange	Cooper and Shull (1953)
0.16–0.38%	Kusaie (Rangpur) lime < Valencia (sweet) orange < Sunki mandarin < Citrandarin 4966 < Citraldin 50130 < Willow Leaf mandarin < Cunningham citrange < King mandarin < Kinnow mandarin	Cooper and Shull (1953)
0.02–0.17%	Cleopatra mandarin < Rangpur lime < Koethen sweet orange = rough lemon < standard sour orange < Jochimsen grapefruit < Sampson tangelo	Jones *et al.* (1957)

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TABLE I–1—(CONTINUED)

Scion	Tree Age (Years)	Leaf Age (Months)	Position Leaf Sample	Culture	Special Treatment
Webb Redblush grapefruit	4	5	Not stated	Field	Mean salt and salinity variables
Ruby Red grapefruit	2	4	Nonfruiting shoot	Field	Rio Grande irrigation water
Frost nucellar Eureka lemon	7	Youngest fully matured	Nonfruiting shoot	Field	None
Nucellar Redblush grapefruit	3	Not stated	Nonfruiting shoot	Field	High-salt irrigation water
Mean of 3 grapefruit	Mean, 6–8	6	Nonfruiting shoot	Field	None
Webb Redblush grapefruit	Mean, 6–8	6	Nonfruiting shoot	Field	Mean 3 cultural variables
Mean of 6	Mean, 4,6	3	Nonfruiting shoot	Field	None

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Elemental Concentration Range	Relative Concentration Rank of Rootstocks	Adapted From
	(Sodium Continued)	
0.27, 0.35%	Sour orange < Cleopatra mandarin	Cooper *et al.* (1958)
0.16–0.38%	Rough lemon < Cleopatra mandarin < Pineapple (sweet) orange = sour orange < Gzel (sweet) orange < Precoce de Valence (sweet) orange = Louisiana (sweet) orange = Citrumelo 4475 = Rangpur lime < Highgrove citremon = Rusk citrange = Citrangor 43301-A2 = Cuban shaddock < P.I. 117477 mandarin = Changsha mandarin = Avena blood (sweet) orange = Hamlin (sweet) orange < Sunki mandarin = Rustic citrange = Saunders citrange = Troyer citrange = Sampson tangelo < Pong Koa mandarin = Savage citrange = Thomasville citrangequat < Uvaldi citrange = Ruby Red grapefruit < Palestine sweet lime < Calashu mandarin = Choo Chou Tien Chieh mandarin = Clementine mandarin = Cunningham citrange < Ponkan mandarin = Lou Chang mandarin < Oneco (Ponkan) mandarin = Suenkat (Sunki) mandarin < Dancy mandarin < Brownell citradia < Kinnow mandarin < King mandarin = Calamondin < Sanguinea mandarin < Kara mandarin	Cooper (1961)
0.10–0.56%	Gajanimma (*C. pennivesiculata*) = Rutherford sweet orange < Alemow = Rangpur lime < Nanshô-daidai = Royal grapefruit < Yuzu	Embleton, Labanauskas, and Bitters (1962)
0.16–0.60%	Sour orange < Rangpur lime < Columbian sweet lime < Alemow < Gajanimma < Savage citrange < Carrizo citrange < Cleopatra mandarin < Troyer citrange < Sunki mandarin < Timkat mandarin < Ponkan mandarin < Citrumelo 4475	Peynado and Young (1962)
0.057, 0.063%	Sour orange < Cleopatra mandarin	Leyden (1963)
0.050, 0.063%	Cleopatra mandarin < sour orange	Leyden (1963)
0.023–0.029%	Stow grapefruit < Oliveland sweet orange < Keen sour orange = Sampson tangelo < Troyer citrange < Cleopatra mandarin	Unpublished data Labanauskas, Bitters and Kirkpatrick†

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TABLE I–2

SPECIFIC ROOTSTOCK COMPARISONS FOR EFFECTS ON CONCENTRATION OF ELEMENTS IN SCION LEAVES; COMPILED FROM TABLE I–1; ROOTSTOCK COMPARISON FOR THOSE THAT OCCUR THREE OR MORE TIMES UNDER A GIVEN ELEMENT IN TABLE I–1

Column 1	Column 2	Number of Comparisons of Rootstocks in Column 1 which Resulted in Lower Leaf Concentration than Rootstock in Column 2	Number of Comparisons of Rootstocks in Column 1 Equal to or in Bracket with Leaf Concentrations of Rootstock in Column 2	Number of Comparisons of Rootstocks in Column 1 which Resulted in Higher Leaf Concentration than Rootstock in Column 2
Nitrogen				
Trifoliate orange	Cleopatra mandarin	1	0	0
Trifoliate orange	Sampson tangelo	1	0	0
Trifoliate orange	Sour orange	1	1	1
Trifoliate orange	Grapefruit	3	0	0
Trifoliate orange	Sweet orange	2	0	1
Trifoliate orange	Rough lemon	3	0	0
Cleopatra mandarin	Sampson tangelo	1	0	1
Cleopatra mandarin	Sour orange	3	1	2
Cleopatra mandarin	Grapefruit	3	0	0
Cleopatra mandarin	Sweet orange	5	0	0
Cleopatra mandarin	Rough lemon	3	0	0
Sampson tangelo	Sour orange	2	0	1
Sampson tangelo	Grapefruit	3	0	0
Sampson tangelo	Sweet orange	3	0	0
Sampson tangelo	Rough lemon	2	0	0
Sour orange	Grapefruit	5	0	1
Sour orange	Sweet orange	6	0	1
Sour orange	Rough lemon	5	0	1
Grapefruit	Sweet orange	3	0	2
Grapefruit	Rough lemon	3	1	1
Sweet orange	Rough lemon	3	2	2
Phosphorus				
Sour orange	Rough lemon	6	2	0
Sour orange	Cleopatra mandarin	5	1	1
Sour orange	Sweet orange	7	2	0
Sour orange	Sampson tangelo	4	0	0
Sour orange	Grapefruit	7	1	0
Sour orange	Trifoliate orange	3	1	0
Rough lemon	Cleopatra mandarin	2	0	2
Rough lemon	Sweet orange	7	0	2
Rough lemon	Sampson tangelo	2	0	1
Rough lemon	Grapefruit	5	1	1
Rough lemon	Trifoliate orange	3	0	1
Cleopatra mandarin	Sweet orange	5	0	1
Cleopatra mandarin	Sampson tangelo	3	0	0
Cleopatra mandarin	Grapefruit	4	0	0
Cleopatra mandarin	Trifoliate orange	1	0	0
Sweet orange	Sampson tangelo	2	1	1
Sweet orange	Grapefruit	3	3	2
Sweet orange	Trifoliate orange	2	1	1

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Column 1	Column 2	Number of Comparisons of Rootstocks in Column 1 which Resulted in Lower Leaf Concentration than Rootstock in Column 2	Number of Comparisons of Rootstocks in Column 1 Equal to or in Bracket with Leaf Concentrations of Rootstock in Column 2	Number of Comparisons of Rootstocks in Column 1 which Resulted in Higher Leaf Concentration than Rootstock in Column 2
Sampson tangelo	Grapefruit	1	2	1
Sampson tangelo	Trifoliate orange	1	0	0
Grapefruit	Trifoliate orange	3	0	1
Potassium				
Cleopatra mandarin	Sour orange	10	1	2
Cleopatra mandarin	Rough lemon	4	1	2
Cleopatra mandarin	Trifoliate orange	1	0	0
Cleopatra mandarin	Sweet orange	7	0	1
Cleopatra mandarin	Grapefruit	5	0	0
Cleopatra mandarin	Rangpur lime	4	0	0
Cleopatra mandarin	Rusk citrange	2	0	1
Cleopatra mandarin	Sampson tangelo	6	0	0
Sour orange	Rough lemon	4	3	3
Sour orange	Trifoliate orange	1	0	0
Sour orange	Sweet orange	9	1	1
Sour orange	Grapefruit	9	0	0
Sour orange	Rangpur lime	4	0	0
Sour orange	Rusk citrange	2	0	1
Sour orange	Sampson tangelo	7	0	0
Rough lemon	Trifoliate orange	2	0	1
Rough lemon	Sweet orange	7	0	4
Rough lemon	Grapefruit	5	0	1
Rough lemon	Rangpur lime	4	0	1
Rough lemon	Rusk citrange	2	0	1
Rough lemon	Sampson tangelo	5	0	1
Trifoliate orange	Sweet orange	3	0	0
Trifoliate orange	Grapefruit	3	0	0
Trifoliate orange	Rangpur lime	0	0	0
Trifoliate orange	Rusk citrange	0	0	0
Trifoliate orange	Sampson tangelo	1	0	0
Sweet orange	Grapefruit	8	0	0
Sweet orange	Rangpur lime	3	0	2
Sweet orange	Rusk citrange	2	0	1
Sweet orange	Sampson tangelo	7	0	0
Grapefruit	Rangpur lime	1	0	0
Grapefruit	Rusk citrange	0	0	1
Grapefruit	Sampson tangelo	4	0	1
Rangpur lime	Rusk citrange	1	1	0
Rangpur lime	Sampson tangelo	2	0	1
Rusk citrange	Sampson tangelo	2	0	0
Calcium				
Rusk citrange	Rough lemon	3	0	0
Rusk citrange	Sweet orange	1	0	2
Rusk citrange	Rangpur lime	1	0	1
Rusk citrange	Grapefruit	0	0	1
Rusk citrange	Trifoliate orange	0	0	0

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TABLE I-2—(CONTINUED)

Column 1	Column 2	Number of Comparisons of Rootstocks in Column 1 which Resulted in Lower Leaf Concentration than Rootstock in Column 2	Number of Comparisons of Rootstocks in Column 1 Equal to or in Bracket with Leaf Concentrations of Rootstock in Column 2	Number of Comparisons of Rootstocks in Column 1 which Resulted in Higher Leaf Concentration than Rootstock in Column 2
Rusk citrange	Sampson tangelo	2	0	0
Rusk citrange	Sour orange	0	2	1
Rusk citrange	Cleopatra mandarin	2	0	1
Rough lemon	Sweet orange	7	1	3
Rough lemon	Rangpur lime	2	1	2
Rough lemon	Grapefruit	5	0	2
Rough lemon	Trifoliate orange	2	0	1
Rough lemon	Sampson tangelo	5	0	1
Rough lemon	Sour orange	5	0	5
Rough lemon	Cleopatra mandarin	5	0	1
Sweet orange	Rangpur lime	3	0	3
Sweet orange	Grapefruit	5	2	2
Sweet orange	Trifoliate orange	2	0	0
Sweet orange	Sampson tangelo	5	1	1
Sweet orange	Sour orange	9	1	2
Sweet orange	Cleopatra mandarin	8	0	0
Rangpur lime	Grapefruit	2	0	0
Rangpur lime	Trifoliate orange	0	0	0
Rangpur lime	Sampson tangelo	2	0	1
Rangpur lime	Sour orange	2	0	2
Rangpur lime	Cleopatra mandarin	3	0	0
Grapefruit	Trifoliate orange	2	0	0
Grapefruit	Sampson tangelo	3	0	2
Grapefruit	Sour orange	4	1	3
Grapefruit	Cleopatra mandarin	4	0	0
Trifoliate orange	Sampson tangelo	0	0	0
Trifoliate orange	Sour orange	2	0	0
Trifoliate orange	Cleopatra mandarin	0	0	0
Sampson tangelo	Sour orange	4	0	3
Sampson tangelo	Cleopatra mandarin	5	0	0
Sour orange	Cleopatra mandarin	10	0	1
Magnesium				
Grapefruit	Rangpur lime	1	0	1
Grapefruit	Sweet orange	7	0	1
Grapefruit	Sour orange	5	2	0
Grapefruit	Sampson tangelo	5	0	0
Grapefruit	Cleopatra mandarin	5	0	0
Grapefruit	Trifoliate orange	2	0	0
Grapefruit	Rusk citrange	1	0	0
Grapefruit	Rough lemon	5	1	0
Rangpur lime	Sweet orange	4	0	2
Rangpur lime	Sour orange	3	0	1
Rangpur lime	Sampson tangelo	1	0	1
Rangpur lime	Cleopatra mandarin	1	0	2
Rangpur lime	Trifoliate orange	0	0	0
Rangpur lime	Rusk citrange	1	0	1
Rangpur lime	Rough lemon	4	0	1

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Column 1	Column 2	Number of Comparisons of Rootstocks in Column 1 which Resulted in Higher Leaf Concentration than Rootstock in Column 2	Number of Comparisons of Rootstocks in Column 1 Equal to or in Bracket with Leaf Concentrations of Rootstock in Column 2	Number of Comparisons of Rootstocks in Column 1 which Resulted in Lower Leaf Concentration than Rootstock in Column 2
Sweet orange	Sour orange	6	3	1
Sweet orange	Sampson tangelo	6	0	1
Sweet orange	Cleopatra mandarin	7	0	2
Sweet orange	Trifoliate orange	2	0	0
Sweet orange	Rusk citrange	3	0	0
Sweet orange	Rough lemon	8	0	1
Sour orange	Sampson tangelo	2	2	2
Sour orange	Cleopatra mandarin	7	1	3
Sour orange	Trifoliate orange	2	0	0
Sour orange	Rusk citrange	2	0	1
Sour orange	Rough lemon	7	0	1
Sampson tangelo	Cleopatra mandarin	5	0	1
Sampson tangelo	Trifoliate orange	1	0	0
Sampson tangelo	Rusk citrange	2	0	0
Sampson tangelo	Rough lemon	5	0	1
Cleopatra mandarin	Trifoliate orange	1	0	0
Cleopatra mandarin	Rusk citrange	2	0	0
Cleopatra mandarin	Rough lemon	4	0	1
Trifoliate orange	Rusk citrange	0	0	0
Trifoliate orange	Rough lemon	1	0	1
Rusk citrange	Rough lemon	2	0	1
Sulfur				
Cleopatra mandarin	Sour orange	2	0	2
Cleopatra mandarin	Sweet orange	2	0	0
Cleopatra mandarin	Grapefruit	2	0	0
Sour orange	Sweet orange	1	0	1
Sour orange	Grapefruit	2	0	0
Sweet orange	Grapefruit	2	0	0
Boron				
Alemow	Gajanimma	3	0	0
Alemow	*Severinia buxifolia*	0	0	0
Alemow	Sour orange	4	0	0
Alemow	Calamondin	0	0	0
Alemow	Sweet orange	1	0	0
Alemow	Yuzu	1	0	0
Alemow	Rough lemon	0	0	0
Alemow	Grapefruit	1	0	0
Alemow	Rangpur lime	3	0	0
Alemow	Troyer citrange	2	0	0
Alemow	Savage citrange	2	0	0
Alemow	Cleopatra mandarin	2	0	0
Alemow	Rusk citrange	0	0	0
Alemow	Sunki mandarin	2	0	0
Alemow	Sweet lemon	0	0	0
Alemow	Trifoliate orange	0	0	0
Alemow	Citrumelo 4475	1	0	0
Alemow	Ponkan mandarin	2	0	0

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TABLE I–2—(CONTINUED)

Column 1	Column 2	Number of Comparisons of Rootstocks in Column 1 which Resulted in Lower Leaf Concentration than Rootstock in Column 2	Number of Comparisons of Rootstocks in Column 1 Equal to or in Bracket with Leaf Concentrations of Rootstock in Column 2	Number of Comparisons of Rootstocks in Column 1 which Resulted in Higher Leaf Concentration than Rootstock in Column 2
Alemow	Sampson tangelo	0	0	0
Alemow	Cuban shaddock	0	0	0
Alemow	Sweet lime	2	0	0
Gajanimma	*Severinia buxifolia*	0	0	0
Gajanimma	Sour orange	2	0	0
Gajanimma	Calamondin	0	0	0
Gajanimma	Sweet orange	1	0	0
Gajanimma	Yuzu	1	0	0
Gajanimma	Rough lemon	0	0	0
Gajanimma	Grapefruit	1	0	0
Gajanimma	Rangpur lime	3	0	0
Gajanimma	Troyer citrange	2	0	0
Gajanimma	Savage citrange	2	0	0
Gajanimma	Cleopatra mandarin	2	0	0
Gajanimma	Rusk citrange	0	0	0
Gajanimma	Sunki mandarin	1	0	0
Gajanimma	Sweet lemon	0	0	0
Gajanimma	Trifoliate orange	0	0	0
Gajanimma	Citrumelo 4475	2	0	0
Gajanimma	Ponkan mandarin	2	0	0
Gajanimma	Sampson tangelo	0	0	0
Gajanimma	Cuban shaddock	0	0	0
Gajanimma	Sweet lime	2	0	0
Severinia buxifolia	Sour orange	3	0	1
Severinia buxifolia	Calamondin	2	0	0
Severinia buxifolia	Sweet orange	4	0	0
Severinia buxifolia	Yuzu	0	0	0
Severinia buxifolia	Rough lemon	1	0	2
Severinia buxifolia	Grapefruit	1	0	1
Severinia buxifolia	Rangpur lime	3	0	0
Severinia buxifolia	Troyer citrange	0	0	0
Severinia buxifolia	Savage citrange	0	0	0
Severinia buxifolia	Cleopatra mandarin	3	0	0
Severinia buxifolia	Rusk citrange	1	0	1
Severinia buxifolia	Sunki mandarin	0	0	0
Severinia buxifolia	Sweet lemon	3	0	1
Severinia buxifolia	Trifoliate orange	2	0	0
Severinia buxifolia	Citrumelo 4475	2	0	0
Severinia buxifolia	Ponkan mandarin	0	0	0
Severinia buxifolia	Sampson tangelo	2	0	0
Severinia buxifolia	Cuban shaddock	0	0	0
Severinia buxifolia	Sweet lime	3	0	0
Sour orange	Calamondin	4	3	0
Sour orange	Sweet orange	13	2	2
Sour orange	Yuzu	3	0	0
Sour orange	Rough lemon	8	0	2
Sour orange	Grapefruit	11	0	3
Sour orange	Rangpur lime	6	0	1
Sour orange	Troyer citrange	3	0	1
Sour orange	Savage citrange	3	0	1
Sour orange	Cleopatra mandarin	14	1	3
Sour orange	Rusk citrange	4	0	2
Sour orange	Sunki mandarin	6	0	1

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Column 1	Column 2	Number of Comparisons of Rootstocks in Column 1 which Resulted in Higher Leaf Concentration than Rootstock in Column 2	Number of Comparisons of Rootstocks in Column 1 Equal to or in Bracket with Leaf Concentrations of Rootstock in Column 2	Number of Comparisons of Rootstocks in Column 1 which Resulted in Lower Leaf Concentration than Rootstock in Column 2
Sour orange	Sweet lemon	9	0	0
Sour orange	Trifoliate orange	8	0	1
Sour orange	Citrumelo 4475	4	0	1
Sour orange	Ponkan mandarin	2	0	1
Sour orange	Sampson tangelo	4	0	1
Sour orange	Cuban shaddock	6	0	0
Sour orange	Sweet lime	5	0	1
Calamondin	Sweet orange	4	1	1
Calamondin	Yuzu	3	0	0
Calamondin	Rough lemon	2	0	1
Calamondin	Grapefruit	5	0	1
Calamondin	Rangpur lime	2	0	0
Calamondin	Troyer citrange	0	0	0
Calamondin	Savage citrange	0	0	0
Calamondin	Cleopatra mandarin	3	0	1
Calamondin	Rusk citrange	3	0	2
Calamondin	Sunki mandarin	3	0	0
Calamondin	Sweet lemon	5	0	1
Calamondin	Trifoliate orange	6	0	1
Calamondin	Citrumelo 4475	2	0	0
Calamondin	Ponkan mandarin	0	0	0
Calamondin	Sampson tangelo	2	0	0
Calamondin	Cuban shaddock	5	0	0
Calamondin	Sweet lime	2	0	0
Sweet orange	Yuzu	2	1	0
Sweet orange	Rough lemon	7	1	3
Sweet orange	Grapefruit	9	0	4
Sweet orange	Rangpur lime	3	1	2
Sweet orange	Troyer citrange	2	0	0
Sweet orange	Savage citrange	2	0	0
Sweet orange	Cleopatra mandarin	7	1	3
Sweet orange	Rusk citrange	4	1	1
Sweet orange	Sunki mandarin	3	1	0
Sweet orange	Sweet lemon	4	1	3
Sweet orange	Trifoliate orange	6	1	1
Sweet orange	Citrumelo 4475	1	2	0
Sweet orange	Ponkan mandarin	1	0	0
Sweet orange	Sampson tangelo	5	0	0
Sweet orange	Cuban shaddock	5	0	0
Sweet orange	Sweet lime	4	0	0
Yuzu	Rough lemon	1	0	0
Yuzu	Grapefruit	3	0	1
Yuzu	Rangpur lime	0	0	0
Yuzu	Troyer citrange	0	0	0
Yuzu	Savage citrange	0	0	0
Yuzu	Cleopatra mandarin	0	0	1
Yuzu	Rusk citrange	1	0	1
Yuzu	Sunki mandarin	1	1	1
Yuzu	Sweet lemon	0	0	0
Yuzu	Trifoliate orange	3	0	0
Yuzu	Citrumelo 4475	0	0	0
Yuzu	Ponkan mandarin	0	0	0
Yuzu	Sampson tangelo	0	0	0

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TABLE I–2—(CONTINUED)

Column 1	Column 2	Number of Comparisons of Rootstocks in Column 1 which Resulted in Lower Leaf Concentration than Rootstock in Column 2	Number of Comparisons of Rootstocks in Column 1 Equal to or in Bracket with Leaf Concentrations of Rootstock in Column 2	Number of Comparisons of Rootstocks in Column 1 which Resulted in Higher Leaf Concentration than Rootstock in Column 2
Yuzu	Cuban shaddock	3	0	0
Yuzu	Sweet lemon	2	0	1
Rough lemon	Grapefruit	4	0	4
Rough lemon	Rangpur lime	3	0	2
Rough lemon	Troyer citrange	0	0	1
Rough lemon	Savage citrange	1	1	1
Rough lemon	Cleopatra mandarin	5	0	5
Rough lemon	Rusk citrange	4	0	2
Rough lemon	Sunki mandarin	0	1	1
Rough lemon	Sweet lemon	2	1	2
Rough lemon	Trifoliate orange	4	0	1
Rough lemon	Citrumelo 4475	2	0	1
Rough lemon	Ponkan mandarin	0	0	1
Rough lemon	Sampson tangelo	2	0	2
Rough lemon	Cuban shaddock	3	0	0
Rough lemon	Sweet lime	4	0	0
Grapefruit	Rangpur lime	3	0	1
Grapefruit	Troyer citrange	1	0	1
Grapefruit	Savage citrange	1	1	0
Grapefruit	Cleopatra mandarin	4	1	4
Grapefruit	Rusk citrange	5	2	0
Grapefruit	Sunki mandarin	3	0	2
Grapefruit	Sweet lemon	5	0	1
Grapefruit	Trifoliate orange	9	0	0
Grapefruit	Citrumelo 4475	2	1	0
Grapefruit	Ponkan mandarin	0	1	0
Grapefruit	Sampson tangelo	4	1	0
Grapefruit	Cuban shaddock	6	0	0
Grapefruit	Sweet lime	3	0	0
Rangpur lime	Troyer citrange	2	0	1
Rangpur lime	Savage citrange	2	0	1
Rangpur lime	Cleopatra mandarin	4	0	2
Rangpur lime	Rusk citrange	0	0	3
Rangpur lime	Sunki mandarin	2	0	1
Rangpur lime	Sweet lemon	2	0	2
Rangpur lime	Trifoliate orange	0	0	2
Rangpur lime	Citrumelo 4475	4	0	1
Rangpur lime	Ponkan mandarin	2	0	1
Rangpur lime	Sampson tangelo	2	0	1
Rangpur lime	Cuban shaddock	1	0	0
Rangpur lime	Sweet lime	4	0	2
Troyer citrange	Savage citrange	2	0	1
Troyer citrange	Cleopatra mandarin	2	0	2
Troyer citrange	Rusk citrange	1	0	0
Troyer citrange	Sunki mandarin	2	0	1
Troyer citrange	Sweet lemon	0	0	0
Troyer citrange	Trifoliate orange	0	0	0
Troyer citrange	Citrumelo 4475	3	0	0
Troyer citrange	Ponkan mandarin	3	0	0
Troyer citrange	Sampson tangelo	2	0	0
Troyer citrange	Cuban shaddock	1	0	0
Troyer citrange	Sweet lime	1	0	2

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Column 1	Column 2	Number of Comparisons of Rootstocks in Column 1 which Resulted in Lower Leaf Concentration than Rootstock in Column 2	Number of Comparisons of Rootstocks in Column 1 Equal to or in Bracket with Leaf Concentrations of Rootstock in Column 2	Number of Comparisons of Rootstocks in Column 1 which Resulted in Higher Leaf Concentration than Rootstock in Column 2
Savage citrange	Cleopatra mandarin	3	0	1
Savage citrange	Rusk citrange	0	0	1
Savage citrange	Sunki mandarin	2	0	1
Savage citrange	Sweet lemon	0	0	0
Savage citrange	Trifoliate orange	1	0	0
Savage citrange	Citrumelo 4475	1	0	2
Savage citrange	Ponkan mandarin	2	0	1
Savage citrange	Sampson tangelo	0	0	2
Savage citrange	Cuban shaddock	1	0	0
Savage citrange	Sweet lime	1	0	2
Cleopatra mandarin	Rusk citrange	4	0	2
Cleopatra mandarin	Sunki mandarin	3	0	1
Cleopatra mandarin	Sweet lemon	3	0	2
Cleopatra mandarin	Trifoliate orange	2	1	2
Cleopatra mandarin	Citrumelo 4475	3	0	2
Cleopatra mandarin	Ponkan mandarin	3	0	0
Cleopatra mandarin	Sampson tangelo	3	0	2
Cleopatra mandarin	Cuban shaddock	3	0	0
Cleopatra mandarin	Sweet lime	3	0	3
Rusk citrange	Sunki mandarin	2	0	1
Rusk citrange	Sweet lemon	3	0	1
Rusk citrange	Trifoliate orange	4	0	1
Rusk citrange	Citrumelo 4475	2	0	1
Rusk citrange	Ponkan mandarin	0	0	1
Rusk citrange	Sampson tangelo	2	1	0
Rusk citrange	Cuban shaddock	4	0	0
Rusk citrange	Sweet lime	3	0	0
Sunki mandarin	Sweet lemon	3	0	1
Sunki mandarin	Trifoliate orange	4	0	0
Sunki mandarin	Citrumelo 4475	2	0	1
Sunki mandarin	Ponkan mandarin	2	0	1
Sunki mandarin	Sampson tangelo	0	0	1
Sunki mandarin	Cuban shaddock	4	0	1
Sunki mandarin	Sweet lime	1	0	1
Sweet lemon	Trifoliate orange	4	1	1
Sweet lemon	Citrumelo 4475	1	0	1
Sweet lemon	Ponkan mandarin	0	0	0
Sweet lemon	Sampson tangelo	2	0	0
Sweet lemon	Cuban shaddock	3	0	1
Sweet lemon	Sweet lime	2	0	1
Trifoliate orange	Citrumelo 4475	2	0	0
Trifoliate orange	Ponkan mandarin	0	0	0
Trifoliate orange	Sampson tangelo	2	0	1
Trifoliate orange	Cuban shaddock	4	0	1
Trifoliate orange	Sweet lime	2	0	0
Citrumelo 4475	Ponkan mandarin	2	0	1
Citrumelo 4475	Sampson tangelo	3	0	0
Citrumelo 4475	Cuban shaddock	1	0	0
Citrumelo 4475	Sweet lime	3	0	2

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TABLE I–2—(CONTINUED)

Column 1	Column 2	Number of Comparisons of Rootstocks in Column 1 which Resulted in Lower Leaf Concentration than Rootstock in Column 2	Number of Comparisons of Rootstocks in Column 1 Equal to or in Bracket with Leaf Concentrations of Rootstock in Column 2	Number of Comparisons of Rootstocks in Column 1 which Resulted in Higher Leaf Concentration than Rootstock in Column 2
Ponkan mandarin	Sampson tangelo	1	0	0
Ponkan mandarin	Cuban shaddock	1	0	0
Ponkan mandarin	Sweet lime	1	0	2
Sampson tangelo	Cuban shaddock	1	0	0
Sampson tangelo	Sweet lime	3	0	0
Cuban shaddock	Sweet lime	1	0	0
Iron				
Trifoliate orange	Grapefruit	2	0	1
Trifoliate orange	Sweet orange	2	0	1
Trifoliate orange	Sour orange	2	0	1
Trifoliate orange	Rough lemon	3	0	0
Grapefruit	Sweet orange	4	0	2
Grapefruit	Sour orange	3	0	2
Grapefruit	Rough lemon	3	0	1
Sweet orange	Sour orange	4	1	3
Sweet orange	Rough lemon	4	0	1
Sour orange	Rough lemon	3	0	1
Manganese				
Sweet orange	Grapefruit	3	0	0
Sweet orange	Sour orange	2	0	1
Sweet orange	Rough lemon	2	1	0
Sweet orange	Cleopatra mandarin	2	0	1
Grapefruit	Sour orange	1	1	0
Grapefruit	Rough lemon	1	0	0
Grapefruit	Cleopatra mandarin	1	1	0
Sour orange	Rough lemon	2	0	0
Sour orange	Cleopatra mandarin	1	2	0
Rough lemon	Cleopatra mandarin	1	0	1
Zinc				
Sour orange	Sweet orange	2	1	0
Sour orange	Rough lemon	2	0	0
Sour orange	Grapefruit	1	1	0
Sour orange	Cleopatra mandarin	2	0	1
Sweet orange	Rough lemon	1	1	1
Sweet orange	Grapefruit	1	1	0
Sweet orange	Cleopatra mandarin	1	0	2
Rough lemon	Grapefruit	1	0	0
Rough lemon	Cleopatra mandarin	1	1	0
Grapefruit	Cleopatra mandarin	1	0	1
Copper				
Sour orange	Grapefruit	1	0	1

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Sour orange	Cleopatra mandarin	1	1	1
Sour orange	Rough lemon	2	0	0
Sour orange	Sweet orange	2	0	0
Grapefruit	Cleopatra mandarin	1	0	1
Grapefruit	Rough lemon	0	0	1
Grapefruit	Sweet orange	2	0	0
Cleopatra mandarin	Rough lemon	2	0	0
Cleopatra mandarin	Sweet orange	3	0	0
Rough lemon	Sweet orange	2	1	0
Chlorine				
Sunki mandarin	Grapefruit	2	0	1
Sunki mandarin	Cleopatra mandarin	3	1	0
Sunki mandarin	Rangpur lime	3	1	0
Sunki mandarin	Sampson tangelo	0	1	1
Sunki mandarin	Rough lemon	1	1	0
Sunki mandarin	Sour orange	3	1	0
Sunki mandarin	Ponkan mandarin	1	2	0
Sunki mandarin	Citrumelo 4475	4	0	0
Sunki mandarin	Trifoliate orange	0	0	0
Sunki mandarin	Cuban shaddock	2	0	0
Sunki mandarin	Calamondin	2	0	0
Sunki mandarin	Sweet orange	2	0	0
Sunki mandarin	Savage citrange	4	0	0
Sunki mandarin	Rusk citrange	2	0	0
Sunki mandarin	Troyer citrange	4	0	0
Grapefruit	Cleopatra mandarin	2	0	1
Grapefruit	Rangpur lime	1	0	1
Grapefruit	Sampson tangelo	2	0	1
Grapefruit	Rough lemon	1	0	1
Grapefruit	Sour orange	2	0	2
Grapefruit	Ponkan mandarin	1	0	1
Grapefruit	Citrumelo 4475	1	0	1
Grapefruit	Trifoliate orange	0	0	0
Grapefruit	Cuban shaddock	3	0	0
Grapefruit	Calamondin	1	0	1
Grapefruit	Sweet orange	2	2	0
Grapefruit	Savage citrange	2	0	0
Grapefruit	Rusk citrange	2	0	0
Grapefruit	Troyer citrange	2	0	1
Cleopatra mandarin	Rangpur lime	3	1	3
Cleopatra mandarin	Sampson tangelo	3	0	2
Cleopatra mandarin	Rough lemon	4	0	0
Cleopatra mandarin	Sour orange	11	0	1
Cleopatra mandarin	Ponkan mandarin	2	2	0
Cleopatra mandarin	Citrumelo 4475	4	0	0
Cleopatra mandarin	Trifoliate orange	0	0	0
Cleopatra mandarin	Cuban shaddock	3	0	0
Cleopatra mandarin	Calamondin	5	0	0
Cleopatra mandarin	Sweet orange	4	0	1

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TABLE I–2—(CONTINUED)

Column 1	Column 2	Number of Comparisons of Rootstocks in Column 1 which Resulted in Lower Leaf Concentration than Rootstock in Column 2	Number of Comparisons of Rootstocks in Column 1 Equal to or in Bracket with Leaf Concentrations of Rootstock in Column 2	Number of Comparisons of Rootstocks in Column 1 which Resulted in Higher Leaf Concentration than Rootstock in Column 2
Cleopatra mandarin	Savage citrange	4	0	0
Cleopatra mandarin	Rusk citrange	5	0	0
Cleopatra mandarin	Troyer citrange	4	0	1
Rangpur lime	Sampson tangelo	3	0	1
Rangpur lime	Rough lemon	5	0	0
Rangpur lime	Sour orange	7	0	0
Rangpur lime	Ponkan mandarin	2	2	0
Rangpur lime	Citrumelo 4475	4	0	0
Rangpur lime	Trifoliate orange	0	0	0
Rangpur lime	Cuban shaddock	3	0	0
Rangpur lime	Calamondin	4	0	0
Rangpur lime	Sweet orange	4	0	0
Rangpur lime	Savage citrange	4	0	0
Rangpur lime	Rusk citrange	4	0	0
Rangpur lime	Troyer citrange	4	0	0
Sampson tangelo	Rough lemon	3	0	1
Sampson tangelo	Sour orange	5	0	1
Sampson tangelo	Ponkan mandarin	0	2	0
Sampson tangelo	Citrumelo 4475	2	0	0
Sampson tangelo	Trifoliate orange	0	0	0
Sampson tangelo	Cuban shaddock	3	0	0
Sampson tangelo	Calamondin	4	0	0
Sampson tangelo	Sweet orange	5	0	1
Sampson tangelo	Savage citrange	2	0	0
Sampson tangelo	Rusk citrange	4	0	0
Sampson tangelo	Troyer citrange	2	0	1
Rough lemon	Sour orange	4	0	1
Rough lemon	Ponkan mandarin	0	1	1
Rough lemon	Citrumelo 4475	2	0	0
Rough lemon	Trifoliate orange	2	0	0
Rough lemon	Cuban shaddock	3	0	0
Rough lemon	Calamondin	4	0	0
Rough lemon	Sweet orange	4	0	0
Rough lemon	Savage citrange	2	0	0
Rough lemon	Rusk citrange	4	0	0
Rough lemon	Troyer citrange	2	0	0
Sour orange	Ponkan mandarin	1	1	2
Sour orange	Citrumelo 4475	4	0	1
Sour orange	Trifoliate orange	1	0	0
Sour orange	Cuban shaddock	3	0	1
Sour orange	Calamondin	5	0	0
Sour orange	Sweet orange	6	0	0
Sour orange	Savage citrange	4	0	0
Sour orange	Rusk citrange	5	0	0
Sour orange	Troyer citrange	5	0	0
Ponkan mandarin	Citrumelo 4475	4	0	0
Ponkan mandarin	Trifoliate orange	0	0	0
Ponkan mandarin	Cuban shaddock	1	0	0
Ponkan mandarin	Calamondin	2	0	0
Ponkan mandarin	Sweet orange	2	0	0
Ponkan mandarin	Savage citrange	4	0	0

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Column 1	Column 2	Number of Comparisons of Rootstocks in Column 1 which Resulted in Lower Leaf Concentration than Rootstock in Column 2	Number of Comparisons of Rootstocks in Column 1 Equal to or in Bracket with Leaf Concentrations of Rootstock in Column 2	Number of Comparisons of Rootstocks in Column 1 which Resulted in Higher Leaf Concentration than Rootstock in Column 2
Ponkan mandarin	Rusk citrange	2	0	0
Ponkan mandarin	Troyer citrange	4	0	0
Citrumelo 4475	Trifoliate orange	1	0	0
Citrumelo 4475	Cuban shaddock	1	0	0
Citrumelo 4475	Calamondin	1	0	1
Citrumelo 4475	Sweet orange	0	2	0
Citrumelo 4475	Savage citrange	4	0	0
Citrumelo 4475	Rusk citrange	2	0	0
Citrumelo 4475	Troyer citrange	4	0	0
Trifoliate orange	Cuban shaddock	0	0	0
Trifoliate orange	Calamondin	0	0	0
Trifoliate orange	Sweet orange	0	0	0
Trifoliate orange	Savage citrange	0	0	0
Trifoliate orange	Rusk citrange	0	0	0
Trifoliate orange	Troyer citrange	0	0	0
Cuban shaddock	Calamondin	0	0	3
Cuban shaddock	Sweet orange	3	0	1
Cuban shaddock	Savage citrange	1	0	0
Cuban shaddock	Rusk citrange	2	1	0
Cuban shaddock	Troyer citrange	1	0	0
Calamondin	Sweet orange	2	2	0
Calamondin	Savage citrange	2	0	0
Calamondin	Rusk citrange	5	0	0
Calamondin	Troyer citrange	2	0	0
Sweet orange	Savage citrange	2	0	0
Sweet orange	Rusk citrange	4	0	0
Sweet orange	Troyer citrange	2	0	1
Savage citrange	Rusk citrange	1	0	1
Savage citrange	Troyer citrange	3	0	0
Rusk citrange	Troyer citrange	2	0	0
Sodium				
Sour orange	Cleopatra mandarin	9	1	3
Sour orange	Rusk citrange	2	2	1
Sour orange	Rough lemon	3	1	2
Sour orange	Rangpur lime	4	1	0
Sour orange	Sweet orange	4	1	2
Sour orange	Cuban shaddock	3	0	0
Sour orange	Savage citrange	3	0	0
Sour orange	Citrumelo 4475	3	0	0
Sour orange	Troyer citrange	4	0	0
Sour orange	Sunki mandarin	2	0	0
Sour orange	Grapefruit	3	0	1
Sour orange	Sampson tangelo	5	1	0
Sour orange	Ponkan mandarin	3	0	0
Sour orange	Calamondin	4	0	0
Cleopatra mandarin	Rusk citrange	3	0	2
Cleopatra mandarin	Rough lemon	4	0	2
Cleopatra mandarin	Rangpur lime	4	0	2

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TABLE I–2—(CONTINUED)

Column 1	Column 2	Number of Comparisons of Rootstocks in Column 1 which Resulted in Lower Leaf Concentration than Rootstock in Column 2	Number of Comparisons of Rootstocks in Column 1 Equal to or in Bracket with Leaf Concentrations of Rootstock in Column 2	Number of Comparisons of Rootstocks in Column 1 which Resulted in Higher Leaf Concentration than Rootstock in Column 2
Cleopatra mandarin	Sweet orange	4	1	2
Cleopatra mandarin	Cuban shaddock	2	0	1
Cleopatra mandarin	Savage citrange	1	1	1
Cleopatra mandarin	Citrumelo 4475	3	0	0
Cleopatra mandarin	Troyer citrange	3	0	1
Cleopatra mandarin	Sunki mandarin	3	0	0
Cleopatra mandarin	Grapefruit	4	0	1
Cleopatra mandarin	Sampson tangelo	4	0	2
Cleopatra mandarin	Ponkan mandarin	3	0	0
Cleopatra mandarin	Calamondin	4	0	0
Rusk citrange	Rough lemon	2	1	1
Rusk citrange	Rangpur lime	2	1	1
Rusk citrange	Sweet orange	2	2	0
Rusk citrange	Cuban shaddock	1	2	0
Rusk citrange	Savage citrange	2	0	0
Rusk citrange	Citrumelo 4475	1	0	1
Rusk citrange	Troyer citrange	2	0	0
Rusk citrange	Sunki mandarin	2	0	0
Rusk citrange	Grapefruit	2	0	1
Rusk citrange	Sampson tangelo	4	0	0
Rusk citrange	Ponkan mandarin	3	0	0
Rusk citrange	Calamondin	4	0	0
Rough lemon	Rangpur lime	3	1	1
Rough lemon	Sweet orange	3	2	1
Rough lemon	Cuban shaddock	2	0	1
Rough lemon	Savage citrange	1	0	1
Rough lemon	Citrumelo 4475	2	0	0
Rough lemon	Troyer citrange	2	0	0
Rough lemon	Sunki mandarin	2	0	0
Rough lemon	Grapefruit	4	0	0
Rough lemon	Sampson tangelo	5	0	0
Rough lemon	Ponkan mandarin	2	0	0
Rough lemon	Calamondin	4	0	0
Rangpur lime	Sweet orange	3	2	1
Rangpur lime	Cuban shaddock	2	0	1
Rangpur lime	Savage citrange	2	0	1
Rangpur lime	Citrumelo 4475	1	1	1
Rangpur lime	Troyer citrange	2	1	0
Rangpur lime	Sunki mandarin	4	0	0
Rangpur lime	Grapefruit	4	0	0
Rangpur lime	Sampson tangelo	4	0	0
Rangpur lime	Ponkan mandarin	3	0	0
Rangpur lime	Calamondin	4	0	0
Sweet orange	Cuban shaddock	1	2	0
Sweet orange	Savage citrange	1	1	0
Sweet orange	Citrumelo 4475	0	2	0
Sweet orange	Troyer citrange	1	1	0
Sweet orange	Sunki mandarin	3	0	0
Sweet orange	Grapefruit	3	0	1
Sweet orange	Sampson tangelo	5	0	0
Sweet orange	Ponkan mandarin	2	0	0
Sweet orange	Calamondin	4	0	0

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Column 1	Column 2	Number of Comparisons of Rootstocks in Column 1 which Resulted in Higher Leaf Concentration than Rootstock in Column 2	Number of Comparisons of Rootstocks in Column 1 Equal to or in Bracket with Leaf Concentrations of Rootstock in Column 2	Number of Comparisons of Rootstocks in Column 1 which Resulted in Lower Leaf Concentration than Rootstock in Column 2
Cuban shaddock	Savage citrange	1	0	0
Cuban shaddock	Citrumelo 4475	0	0	1
Cuban shaddock	Troyer citrange	1	0	0
Cuban shaddock	Sunki mandarin	1	0	0
Cuban shaddock	Grapefruit	1	0	0
Cuban shaddock	Sampson tangelo	3	0	0
Cuban shaddock	Ponkan mandarin	1	0	0
Cuban shaddock	Calamondin	3	0	0
Savage citrange	Citrumelo 4475	2	0	1
Savage citrange	Troyer citrange	2	0	1
Savage citrange	Sunki mandarin	2	1	0
Savage citrange	Grapefruit	2	0	0
Savage citrange	Sampson tangelo	1	0	1
Savage citrange	Ponkan mandarin	3	0	0
Savage citrange	Calamondin	3	0	0
Citrumelo 4475	Troyer citrange	2	0	1
Citrumelo 4475	Sunki mandarin	2	0	1
Citrumelo 4475	Grapefruit	2	0	0
Citrumelo 4475	Sampson tangelo	2	0	0
Citrumelo 4475	Ponkan mandarin	2	0	1
Citrumelo 4475	Calamondin	2	0	0
Troyer citrange	Sunki mandarin	2	1	0
Troyer citrange	Grapefruit	2	0	1
Troyer citrange	Sampson tangelo	1	1	1
Troyer citrange	Ponkan mandarin	3	0	0
Troyer citrange	Calamondin	2	0	0
Sunki mandarin	Grapefruit	1	0	1
Sunki mandarin	Sampson tangelo	0	1	1
Sunki mandarin	Ponkan mandarin	2	1	0
Sunki mandarin	Calamondin	1	0	1
Grapefruit	Sampson tangelo	3	0	1
Grapefruit	Ponkan mandarin	2	0	0
Grapefruit	Calamondin	1	0	1
Sampson tangelo	Ponkan mandarin	2	0	0
Sampson tangelo	Calamondin	3	1	0
Ponkan mandarin	Calamondin	1	0	1

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TABLE I–3

THE EFFECT OF SCION ON THE CONCEN

Rootstock	Tree Age (Years)	Leaf Age (Months)	Position Leaf Sample	Culture	Special Treatment
Mean of 5	Mature	5–6	Fruiting shoot	Field	None
Mean of 5	21	6	Not stated	Field	None
Not stated	2	Young	Not stated	Sand	N variable
Mean of 2	7	3–6	Fruiting shoot	Field	None
Mean of 3	21	3–6	Fruiting shoot	Field	None
Mean of 2	Mean, 6–8	6	Nonfruiting shoot	Field	None
Mean of 2	1	Not stated	Nonfruiting shoot	Nutrient solution	None
Mean of 6	Mean, 4, 6	3	Nonfruiting shoot	Field	None
Mean of 2	Not stated	Mature	Not stated	Field	None
Mean of 5	Mature	5–6	Fruiting shoot	Field	None
Mean of 5	21	6	Not stated	Field	None
Not stated	2	Young	Not stated	Sand	N variable
Mean of 2	7	3–6	Fruiting shoot	Field	None
Mean of 3	21	3–6	Fruiting shoot	Field	None
Mean of 2	Mean, 6–8	6	Nonfruiting shoot	Field	None
Mean of 2	1	Not stated	Nonfruiting shoot	Nutrient solution	None
Mean of 6	Mean, 4, 6	3	Nonfruiting shoot	Field	None
Mean of 2	Not stated	Mature	Not stated	Field	None
Mean of 5	Mature	5–6	Fruiting terminal	Field	None
Mean of 2	1	6–12	Nonfruiting terminal	Field	Mean salt and B variables

* For details on the botany and nomenclature of scions see Hodgson (1967), and Swingle and Reece (1967).

† Unpublished data of C. K. Labanauskas, W. P. Bitters, and J. D. Kirkpatrick, University of California, Riverside.

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TRATION OF ELEMENTS IN SCION LEAVES

Elemental Concentration Range	Relative Concentration Rank of Scions*	Adapted From
	Nitrogen	
2.32, 2.80%	Valencia orange < Washington navel orange	Chapman and Brown (1950)
2.57–2.94%	Sour orange = Eureka lemon < rough lemon < Marsh grapefruit < trifoliate orange < Valencia orange < Washington navel orange	Wallace, Naude *et al.* (1952)
4.37, 5.08%	Valencia orange < navel orange	Van der Merwe (1952–53)
2.46, 2.68%	Laranja pera (sweet orange, Valencia type) < laranja bahianinha (navel orange)	Gallo *et al.* (1960)
2.37, 2.73%	Laranja pera (sweet orange, Valencia type) < laranja bahianinha (navel orange)	Gallo *et al.* (1960)
2.33–2.37%	Foster grapefruit < Duncan grapefruit < Webb Redblush grapefruit	Leyden (1963)
3.01, 3.33%	Yuzu < trifoliate orange	Saito and Yamamoto (1963)
2.18–2.39%	Prior Lisbon lemon < Rosenberger Lisbon lemon = Monroe Lisbon lemon < Frost nucellar Eureka lemon < Cook nucellar Eureka lemon < Cascade Eureka lemon	Unpublished data Labanauskas, Bitters and Kirkpatrick†
	Phosphorus	
0.118–0.193%	Eureka lemon < Marsh grapefruit < navel orange	Haas (1945b)
0.103, 0.122%	Valencia orange < Washington navel orange	Chapman and Brown (1950)
0.100–0.123%	Rough lemon < trifoliate orange = Eureka lemon < Marsh grapefruit < Washington navel orange < Valencia orange	Wallace, Naude *et al.* (1952)
0.42%	Valencia orange = navel orange	Van der Merwe (1952–53)
0.120, 0.130%	Laranja pera (sweet orange, Valencia type) < laranja bahianinha (navel orange)	Gallo *et al.* (1960)
0.114, 0.119%	Laranja pera (sweet orange, Valencia type) < laranja bahianinha (navel orange)	Gallo *et al.* (1960)
0.12%	Foster grapefruit = Duncan grapefruit = Webb Redblush grapefruit	Leyden (1963)
0.16%	*C. junos* = trifoliate orange	Saito and Yamamoto (1963)
0.181–0.198%	Prior Lisbon lemon < Rosenberger Lisbon lemon < Cook nucellar Eureka lemon < Frost nucellar Eureka lemon < Monroe Lisbon lemon < Cascade Eureka lemon	Unpublished data Labanauskas, Bitters and Kirkpatrick†
	Potassium	
0.82–1.54%	Eureka lemon < Marsh grapefruit < navel orange	Haas (1945b)
0.50, 0.89%	Valencia orange < Washington navel orange	Chapman and Brown (1950)
2.31, 2.56%	Valencia orange < Shary Red grapefruit	Cooper, Gorton and Olson (1952)

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TABLE I-3—(CONTINUED)

Rootstock	Tree Age (Years)	Leaf Age (Months)	Position Leaf Sample	Culture	Special Treatment
Mean of 5	21	6	Not stated	Field	None
Not stated	2	Young	Not stated	Sand	N variable
Mean of 2	11 months	All leaves	Nonfruiting shoot	Flats in glasshouse	None
Mean of 2	7	3–6	Fruiting shoot	Field	None
Mean of 3	21	3–6	Fruiting shoot	Field	None
Mean of 2	Mean, 6–8	6	Nonfruiting shoot	Field	None
Mean of 2	1	Not stated	Nonfruiting shoot	Nutrient solution	None
Mean of 6	Mean, 4, 6	3	Nonfruiting shoot	Field	None
Mean of 2	Not stated	Mature	Not stated	Field	None
Mean of 5	Mature	5–6	Fruiting shoot	Field	None
Mean of 2	1	6–12	Nonfruiting shoot	Field	Mean salt and B variables
Mean of 5	21	6	Not stated	Field	None
Not stated	2	Young	Not stated	Sand	N variable
Mean of 2	11 months	All leaves	Nonfruiting shoot	Flats in glasshouse	None
Mean of 2	7	3–6	Fruiting shoot	Field	None
Mean of 3	21	3–6	Fruiting shoot	Field	None
Mean of 2	Mean, 6–8	6	Nonfruiting shoot	Field	None
Mean of 2	1	Not stated	Nonfruiting shoot	Nutrient solution	None
Mean of 6	Mean, 4, 6	3	Nonfruiting shoot	Field	None
Mean of 2	Not stated	Mature	Not stated	Field	None
Mean of 5	Mature	5–6	Fruiting shoot	Field	None
Mean of 5	21	6	Not stated	Field	None

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Elemental Concentration Range	Relative Concentration Rank of Scions*	Adapted From
	(Potassium continued)	
0.98–1.68%	Sour orange = Eureka lemon < trifoliate orange < rough lemon < Valencia orange < Marsh grapefruit < Washington navel orange	Wallace, Naude *et al.* (1952)
1.59, 2.02%	Valencia < navel orange	Van der Merwe (1952–53)
2.26, 2.82%	Rough lemon < trifoliate orange	Shannon and Zaphrir (1958)
1.28, 2.06%	Laranja pera (sweet orange, Valencia type) < laranja banhianinha (navel orange)	Gallo *et al.* (1960)
0.82, 1.91%	Laranja pera (sweet orange, Valencia type) < laranja bahianinha (navel orange)	Gallo *et al.* (1960)
0.92–0.98%	Webb Redblush grapefruit = Foster grapefruit < Duncan grapefruit	Leyden (1963)
1.88, 3.37%	*C. junos* < trifoliate orange	Saito and Yamamoto (1963)
1.24–1.31%	Prior Lisbon lemon < Rosenberger Lisbon lemon < Cook nucellar Eureka lemon < Frost nucellar Eureka lemon < Monroe Lisbon lemon < Cascade Eureka lemon	Unpublished data Labanauskas, Bitters and Kirkpatrick†
	Calcium	
4.82–7.38%	Navel orange < Marsh grapefruit < Eureka lemon	Haas (1945b)
5.21, 6.18%	Washington navel orange < Valencia orange	Chapman and Brown (1950)
3.64, 3.98%	Valencia orange < Shary Red grapefruit	Cooper, Gorton, and Olson (1952)
3.66–4.96%	Eureka lemon < sour orange < Washington navel orange < Valencia orange < rough lemon < Marsh grapefruit < trifoliate orange	Wallace, Naude *et al.* (1952)
1.23, 1.40%	Navel orange < Valencia orange	Van der Merwe (1952–53)
0.88, 1.26%	Trifoliate orange < rough lemon	Shannon and Zaphrir
3.50, 3.70%	Laranja bahianinha (navel orange) < laranja pera (sweet orange, Valencia type)	Gallo *et al.* (1960)
3.22, 3.26%	Laranja bahianinha (navel orange) < laranja pera (sweet orange, Valencia type)	Gallo *et al.* (1960)
4.92–5.18%	Duncan grapefruit < Foster grapefruit < Webb Redblush grapefruit	Leyden (1963)
2.81, 3.30%	Yuzu < trifoliate orange	Saito and Yamamoto (1963)
2.53–2.84%	Prior Lisbon lemon < Monroe Lisbon lemon < Rosenberger Lisbon lemon < Cook nucellar Eureka lemon < Frost nucellar Eureka lemon < Cascade Eureka lemon	Unpublished data Labanauskas, Bitters and Kirkpatrick†
	Magnesium	
0.34–0.51%	Navel orange < Eureka lemon < Marsh grapefruit	Haas (1945b)
0.40, 0.43%	Washington navel orange < Valencia orange	Chapman and Brown (1950)
0.09–0.20%	Trifoliate orange < Washington navel orange < Eureka lemon < rough lemon < Marsh grapefruit < Valencia orange < sour orange	Wallace, Naude *et al.* (1952)

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TABLE I–3—(CONTINUED)

Scion	Tree Age (Years)	Leaf Age (Months)	Position Leaf Sample	Culture	Special Treatment
Mean of 2	7	3–6	Fruiting shoot	Field	None
Mean of 3	21	3–6	Fruiting shoot	Field	None
Mean of 2	Mean, 6–8	6	Nonfruiting shoot	Field	None
Mean of 2	1	Not stated	Nonfruiting shoot	Nutrient solution	None
Mean of 6	Mean, 4, 6	3	Nonfruiting shoot	Field	None
Mean of 6	Mature	Mature	Nonfruiting shoot	Field	None
Mean of 3	Not stated	Not stated	Not stated	Nursery	None
Mean of 4	Not stated	Not stated	Not stated	Nursery	None
Mean of 6	4	Not stated	Not stated	Field	None
Mean of 2	Not stated	Mature	Nonfruiting shoot	Field	None
Cleopatra mandarin	1	9	Nonfruiting shoot	Field	Mean salt variables
Mean of 2	1	6–12	Nonfruiting shoot	Field	Mean salt and B variables
Mean of 6	Mean, 4, 6	3	Nonfruiting shoot	Field	None
Mean of 2	1	4	Nonfruiting shoot	Solution	Mean 3 Fe levels
Mean of 2	1	Fully expanded	Nonfruiting shoot	Potted soil, glasshouse	Acid soil $CaCO_3$
Mean of 6	Mean, 4, 6	3	Nonfruiting shoot	Field	None
Mean of 6	Mean, 4, 6	3	Nonfruiting shoot	Field	None
Mean of 6	Mean, 4, 6	3	Nonfruiting shoot	Field	None

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Elemental Concentration Range	Relative Concentration Rank of Rootstocks*	Adapted From
	(Mangnesium Continued)	
0.30, 0.34%	Laranja bahianinha (navel orange) < laranja pera (sweet orange, Valencia type)	Gallo *et al.* (1960)
0.24, 0.31%	Laranja bahianinha (navel orange) < laranja pera (sweet orange, Valencia type)	Gallo *et al.* (1960)
0.45–0.52%	Duncan grapefruit < Webb Redblush grapefruit < Foster grapefruit	Leyden (1963)
0.31, 0.50%	Yuzu < trifoliate orange	Saito and Yamamoto (1963)
0.26–0.28%	Cook nucellar Eureka lemon < Cascade Eureka lemon < Prior Lisbon lemon < Monroe Lisbon lemon < Rosenberger Lisbon lemon < Frost nucellar Eureka lemon	Unpublished data Labanauskas, Bitters and Kirkpatrick†
	Sulfur	
0.60, 0.70%	Parson Brown orange < Valencia orange	Rassmussen and Smith (1958)
	Boron	
49–64 ppm	Valencia orange < Dancy tangerine < Duncan grapefruit < Parson Brown orange < Temple orange	Roy (1943)
41–50 ppm	Duncan grapefruit < Parson Brown orange < Temple orange < Dancy tangerine	Roy (1943)
41–63 ppm	Hamlin orange < Pineapple orange < Parson Brown orange < Jaffa orange < Temple orange < Dancy tangerine	Roy (1943)
57, 76 ppm	Marsh grapefruit < Eureka lemon	Haas (1945*a*)
87, 114 ppm	Valencia orange < Redblush grapefruit	Cooper (1948)
448, 482 ppm	Valencia orange < Shary Red grapefruit	Cooper, Gorton, and Olson (1952)
69–77 ppm	Monroe Lisbon lemon < Rosenberger Lisbon lemon < Prior Lisbon lemon < Frost nucellar Eureka lemon < Cook nucellar Eureka lemon = Cascade Eureka lemon	Unpublished data Labanauskas, Bitters and Kirkpatrick†
	Iron	
32, 44 ppm	Standard sour orange < Koethen sweet orange	Wallihan and Garber (1968*a*)
98, 113 ppm	Standard sour orange < Koethen sweet orange	Wallihan and Garber (1968*b*)
35, 37 ppm	Standard sour orange < Koethen sweet orange	
63–71 ppm	Cascade Eureka lemon < Monroe Lisbon lemon < Rosenberger Lisbon lemon < Cook nucellar Eureka lemon < Prior Lisbon lemon < Frost nucellar Eureka lemon	Unpublished data Labanauskas, Bitters and Kirkpatrick†
	Manganese	
15–17 ppm	Monroe Lisbon lemon < Rosenberger Lisbon lemon = Prior Lisbon lemon = Frost nucellar Lisbon lemon < Cook nucellar Eureka lemon = Cascade Eureka lemon	Unpublished data Labanauskas, Bitters and Kirkpatrick†
	Zinc	
18–19 ppm	Rosenberger Lisbon lemon = Monroe Lisbon lemon < Frost nucellar Eureka lemon = Cook nucellar Eureka lemon = Cascade Eureka lemon = Prior Lisbon lemon	Unpublished data Labanauskas, Bitters and Kirkpatrick†

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TABLE I–3—(CONTINUED)

Rootstock	Tree Age (Years)	Leaf Age (Months)	Position Leaf Sample	Culture	Special Treatment
Mean of 6	Mean, 4, 6	3	Nonfruiting shoot	Field	None
Cleopatra mandarin	1	9	Nonfruiting shoot	Field	Mean salt variables
Mean of 2	1	6–12	Nonfruiting shoot	Field	Mean salt and B variables
Cleopatra mandarin	1	Not stated	Nonfruiting shoot	Field	High-salt irrigation water
Sour orange	1	Not stated	Nonfruiting shoot	Field	High-salt irrigation water
Mean of 6	Mean, 4, 6	3	Nonfruiting shoot	Field	None
Cleopatra mandarin	1	9	Nonfruiting shoot	Field	Mean salt variables
Mean of 2	1	6–12	Nonfruiting shoot	Field	Mean salt and B variables
Cleoptra mandarin	1	Not stated	Nonfruiting shoot	Field	High-salt irrigation water
Sour orange	1	Not stated	Nonfruiting shoot	Field	High-salt irrigation water
Mean of 2	Mean, 6–8	6	Nonfruiting shoot	Field	None
Mean of 6	Mean, 4, 6	3	Nonfruiting shoot	Field	None

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Concentration Range	Relative Concentration Rank of Scions*	Adapted from
	Copper	
7.0–8.1 ppm	Prior Lisbon lemon < Rosenberger Lisbon lemon < Monroe Lisbon lemon < Cook nucellar Eureka lemon < Frost nucellar Eureka lemon = Cascade Eureka lemon	Unpublished data Labanauskas, Bitters and Kirkpatrick†
	Chlorine	
0.25, 0.40%	Valencia orange < Redblush grapefruit	Cooper (1948)
0.83, 0.86%	Valencia orange < Shary Red grapefruit	Cooper, Gorton and Olson (1952)
0.70–1.20%	Marsh grapefruit < Hamlin orange < Valencia orange = Clementine mandarin < Ruby Red grapefruit = Shary Red grapefruit	Cooper, Cowley and Shull (1952)
2.10–2.50%	Clementine mandarin < Thomson navel orange < Valencia orange = Eureka lemon = Marsh grapefruit	Cooper, Cowley and Shull (1952)
0.051–0.060%	Monroe Lisbon lemon < Rosenberger Lisbon lemon = Frost nucellar Eureka lemon < Cook nucellar Eureka lemon < Cascade Eureka lemon < Prior Lisbon lemon	Unpublished data Labanauskas, Bitters and Kirkpatrick†
	Sodium	
Trace, 0.58%	Valencia orange < Redblush grapefruit	Cooper (1948)
0.097, 0.166%	Valencia orange < Shary Red grapefruit	Cooper, Gorton and Olson (1952)
0.28–0.48%	Valencia orange < Hamlin orange < Marsh grapefruit < Ruby Red grapefruit	Cooper, Cowley and Shull (1952)
0.14–0.30%	Eureka lemon < Thomson navel orange < Valencia orange < Marsh grapefruit	Cooper, Cowley and Shull (1952)
0.050–0.075%	Foster grapefruit < Webb Redblush grapefruit < Duncan grapefruit	Leyden (1963)
0.020–0.030%	Cascade Eureka lemon < Frost nucellar Eureka lemon < Cook nucellar Eureka lemon < Monroe Lisbon lemon < Prior Lisbon lemon < Rosenberger Lisbon lemon	Unpublished data Labanauskas, Bitters and Kirkpatrick†

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APPENDIX II

MONTHLY TEMPERATURE AND RAINFALL DATA FOR SOME MAJOR CITRUS-PRODUCING REGIONS

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Table II–1

MONTHLY MEAN MAXIMUM AND MEAN MINIMUM TEMPERATURES IN SELECTED UNITED STATES CITRUS-GROWING AREAS

Temperatures (°C)

Location and Temperature Range	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
1.	Homestead University of Florida Experiment Station (Dade), Florida. Latitude, 25°30′N; Elevation 3 m; 1931–60.											
Maximum	25.4	26.2	27.5	29.1	30.7	31.8	32.3	32.7	31.7	29.8	27.4	25.9
Minimum	12.0	12.2	13.7	16.2	18.1	20.5	21.2	21.4	21.5	19.3	15.5	12.9
2.	Lake Placid (Highlands), Florida. Latitude, 27°17′N; Elevation, 27 m; 1939–60.											
Maximum	24.2	25.4	27.3	29.4	32.2	33.3	33.3	33.7	32.5	29.8	26.7	24.4
Minimum	10.4	11.7	13.3	16.0	18.7	20.9	21.9	22.2	21.9	18.3	14.2	11.1
3.	Fort Pierce (St. Lucie), Florida. Latitude, 27°25′N, Elevation, 3 m; 1904–60.											
Maximum	22.9	23.6	25.3	27.1	29.1	31.0	31.8	31.9	30.9	28.5	25.4	23.4
Minimum	13.5	13.7	15.3	17.8	20.3	22.3	23.0	23.3	23.3	21.0	16.9	14.0
4.	Lake Alfred, University of Florida Citrus Experiment Station (Polk), Florida. Latitude, 28°06′N; Elevation, 55 m; 1938–60.											
Maximum	22.9	24.0	26.0	28.5	31.2	32.8	33.1	33.3	31.9	29.3	25.4	23.1
Minimum	9.6	10.3	12.5	15.2	18.1	21.2	22.2	22.2	21.5	17.8	13.0	10.1
5.	Orlando (Orange), Florida, Latitude, 28°33′N; Elevation, 32 m; 1943–60.											
Maximum	22.4	23.5	25.6	28.5	31.3	33.0	33.1	33.2	31.8	28.5	25.3	22.5
Minimum	9.9	10.9	13.0	16.0	19.0	21.8	22.5	22.9	22.2	18.4	13.5	10.2
6.	Ocala (Marion), Florida. Latitude, 29°13′N; Elevation, 21 m; 1943–60.											
Maximum	21.9	22.9	24.9	28.4	31.8	33.2	33.1	33.3	31.9	28.9	25.1	22.0
Minimum	7.1	8.0	10.2	13.4	16.8	20.2	21.2	21.2	20.4	15.9	10.6	7.6
7.	Fairhope (Baldwin), Alabama. Latitude, 30°33′N; Elevation, 7 m; 1918–60.											
Maximum	17.8	19.2	21.6	25.4	29.1	31.6	32.3	32.6	31.0	27.1	21.4	18.2
Minimum	5.9	7.2	9.6	13.3	17.3	21.0	22.1	22.0	20.0	14.4	8.6	6.6
8.	Port Sulfur (Plaquemines), Louisiana. Latitude, 29°29′N; Elevation, 2 m; 1939–60.											
Maximum	19.1	19.7	22.3	25.7	29.2	31.7	32.6	32.6	30.3	27.2	22.0	19.0
Minimum	8.6	9.7	12.2	16.1	19.8	23.0	23.6	23.8	22.4	18.0	12.1	9.1
9.	Brownsville (Cameron), Louisiana. Latitude, 25°54′N; Elevation, 5 m; 1943–60.											
Maximum	21.5	23.3	25.2	28.2	30.8	32.4	33.8	32.1	29.3	25.1	22.5	28.2
Minimum	11.2	13.1	15.4	19.0	22.1	24.0	24.4	24.4	22.8	19.3	14.7	11.9
10.	Weslaco (Hidalgo), Texas. Latitude, 26°09′N; Elevation, 34 m; 1923–60.											
Maximum	22.2	24.6	26.9	30.1	32.2	34.0	34.8	35.7	33.4	30.6	25.8	22.5
Minimum	10.2	11.9	14.6	18.1	20.8	22.7	23.2	23.2	21.8	18.1	13.4	10.8
11.	Carrizo Springs (Dimmit), Texas. Latitude, 28°32′N; Elevation, 198 m; 1924–60.											
Maximum	19.1	21.6	25.7	29.8	32.9	36.0	37.4	37.5	34.3	29.9	23.4	19.6
Minimum	5.5	7.7	10.5	14.8	19.1	22.4	23.2	23.3	20.6	15.9	9.6	6.2
12.	Yuma, University of Arizona Citrus Experiment Station (Yuma), Arizona. Latitude, 32°37′N; Elevation, 58 m; 1922–60.											
Maximum	20.1	22.8	26.1	30.2	34.3	39.2	41.4	40.3	39.3	33.4	25.3	21.0
Minimum	3.7	5.8	8.1	11.3	15.1	19.2	25.0	24.8	20.9	14.1	7.7	5.1
13.	Tempe, University of Arizona Citrus Experiment Station (Maricopa), Arizona. Latitude, 33°23′N; Elevation, 360 m; 1944–1960.											
Maximum	19.0	20.9	24.2	29.1	33.7	39.3	40.2	38.7	38.3	32.0	24.2	20.2
Minimum	1.3	2.6	5.0	8.5	12.1	16.3	22.0	21.5	17.5	11.7	4.6	1.9
14.	Indio, U. S. Date Garden (Riverside), California. Latitude, 33°44′N; Elevation 3 m; 1897–1960.											
Maximum	21.1	23.5	26.7	30.5	34.1	38.8	41.6	40.8	38.6	33.1	27.0	22.1
Minimum	3.4	6.3	9.6	13.8	17.6	21.8	25.2	24.4	20.8	14.5	7.5	5.8

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TABLE II-1—(CONTINUED)

Location and Temperature Range	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
15.	Escondido (San Diego), California. Latitude, 33°07′N; Elevation, 210 m; 1933–60.											
Maximum	18.6	19.2	20.8	22.5	24.4	27.1	31.0	31.2	30.6	26.5	23.5	20.0
Minimum	2.5	3.7	5.5	8.1	10.3	12.2	14.6	14.8	13.3	9.3	4.6	3.2
16.	Riverside (Riverside), California. Latitude, 33°57′N; Elevation, 250 m; 1897–1960.											
Maximum	18.8	19.7	21.5	24.0	26.3	30.3	34.5	34.3	32.9	28.1	24.0	19.8
Minimum	3.2	4.4	5.1	7.5	9.7	11.6	14.0	13.8	12.1	8.7	5.3	3.5
17.	Santa Paula (Ventura), California. Latitude, 34°21′N; Elevation, 86 m; 1947–1960.											
Maximum	19.0	20.7	21.9	22.8	23.5	25.2	28.1	27.2	29.0	26.7	24.3	21.5
Minimum	4.8	5.0	5.4	7.8	9.1	10.7	12.4	12.2	11.7	9.6	7.3	5.9
18.	Santa Barbara (Santa Barbara), California. Latitude, 34°26′N; Elevation, 31 m; 1897–1960.											
Maximum	18.1	19.3	20.2	20.4	22.0	23.5	25.8	25.4	26.4	24.1	22.6	20.2
Minimum	5.3	6.3	7.2	8.6	10.0	11.7	13.5	13.7	12.7	10.4	7.4	5.9
19.	Lindsay (Tulare), California. Latitude, 36°11′N; Elevation, 120 m; 1915–60.											
Maximum	13.7	17.4	20.8	25.2	29.5	34.2	38.1	36.8	33.2	27.1	20.2	14.3
Minimum	1.5	3.1	4.5	7.2	9.7	12.8	15.9	14.7	12.3	8.1	3.2	1.9
20.	Orland (Glenn), California. Latitude, 39°45′N; Elevation, 78 m; 1907–60.											
Maximum	11.8	15.1	18.6	23.0	28.0	32.9	37.1	35.7	31.9	25.8	18.2	12.6
Minimum	2.5	4.2	5.8	8.2	11.5	15.1	17.1	15.6	13.6	10.1	5.5	3.0

Source: Climatography of the United States, Numbers 86–1, 2, 4, 6, 36. Supplements for 1951–60. U. S. Department of Commerce, Weather Bureau. 1964.

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Table II–2

MONTHLY RAINFALL DISTRIBUTION IN SELECTED UNITED STATES CITRUS-GROWING AREAS

Location*	Month												Annual Total (Mm)	Years of Record
	1	2	3	4	5	6	7	8	9	10	11	12		
	Rainfall (Millimeters)†													
1. Homestead, Florida	46	45	56	94	171	215	208	203	247	220	69	35	1,608	1911–1960
2. Lake Placid, Florida	41	56	77	98	98	198	210	167	191	109	43	37	1,325	1935–1960
3. Fort Pierce, Florida	65	63	78	86	107	159	137	146	200	183	73	53	1,349	1895–1960
4. Lake Alfred, Florida	55	65	93	87	111	202	200	178	184	78	37	53	1,343	1925–1960
5. Orlando, Florida	50	57	91	88	80	161	230	180	203	121	39	45	1,339	1943–1960
6. Ocala, Florida	53	68	119	87	78	180	217	186	176	94	48	60	1,364	1943–1960
7. Fairhope, Alabama	113	107	154	139	123	156	210	168	172	96	87	126	1,651	1918–1960
8. Port Sulfur, Louisiana	102	110	117	121	121	166	208	188	240	77	84	116	1,649	1936–1960
9. Brownsville, Texas	33	41	25	35	61	83	35	67	110	94	36	44	661	1937–1960
10. Weslaco, Texas	37	25	27	35	78	63	42	56	99	55	34	33	585	1914–1960
11. Carrizo Springs, Texas	25	24	23	43	84	63	43	56	72	60	24	27	544	1922–1960
12. Yuma, Arizona	9	8	6	3	0	0	6	14	12	9	4	12	82	1922–1960
13. Tempe, Arizona	23	14	17	7	5	3	21	38	15	16	10	17	185	1944–1960
14. Indio, California	17	11	7	3	1	0	2	7	7	5	6	15	80	1878–1960
15. Escondido, California	75	82	65	35	8	2	0	4	6	21	33	82	412	1931–1960
16. Riverside, California	53	53	51	22	9	1	1	4	4	15	19	46	278	1881–1960
17. Santa Paula, California	103	55	64	43	9	1	0	1	1	7	33	54	371	1947–1960
18. Santa Barbara, California	102	93	72	32	11	2	1	1	7	17	36	81	448	1868–1960
19. Lindsay, California	54	51	47	28	12	3	0	0	3	11	24	47	278	1914–1960
20. Orland, California	92	78	60	34	18	9	1	1	10	25	50	85	461	1883–1960

* See Table II–1 for additional information on latitude, altitude, and country.
† Rounded to nearest millimeter. Millimeters × 0.03937 = inches.

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TABLE II–3—(CONTINUED)

Location and Temperature Range	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
21.	Valencia (Valencia), Spain. Latitude, 39½°; Elevation, 24 m.											
Maximum	14.4	15.6	17.2	19.4	22.8	25.6	28.3	28.3	26.7	22.8	18.3	10.6
Minimum	5.0	6.1	8.3	10.6	13.3	17.2	20.0	20.6	17.8	13.9	8.9	5.5
22.	Alicante (Alicante), Spain. Latitude, 38½°; Elevation 35 m.											
Maximum	16.1	16.6	18.9	21.1	23.9	27.2	30.0	30.6	28.4	25.0	19.4	16.6
Minimum	5.0	5.9	7.8	10.0	12.8	16.1	18.9	19.4	17.8	13.9	7.2	6.8
23.	Messina (Sicily), Italy. Latitude, 38°; Elevation 50 m.											
Maximum	13.9	15.0	16.7	18.9	22.8	27.2	30.0	30.0	27.8	23.3	20.0	15.6
Minimum	9.4	8.9	10.0	12.2	15.0	17.8	22.2	22.8	20.6	16.7	13.3	10.6
24.	Taranto (Puglia), Italy. Latitude, 40½°N; Elevation 20 m.											
Maximum	12.8	13.9	15.3	15.2	24.4	28.9	31.6	31.6	28.3	22.8	17.2	14.4
Minimum	5.9	6.3	7.2	10.0	14.4	18.9	21.1	21.1	18.3	14.4	10.6	7.2
25.	Arta (Epirus), Greece. Latitude, 39°N; Elevation 30 m.											
Maximum	12.8	14.4	17.8	21.7	26.2	30.0	33.3	33.9	30.6	24.4	18.3	14.4
Minimum	3.9	4.4	6.7	9.5	13.3	16.7	18.9	18.9	16.7	12.8	8.3	5.6
26.	Chania (Crete), Greece. Latitude, 35½°N; Elevation 20 m.											
Maximum	15.4	15.2	17.8	21.1	23.9	27.8	30.0	30.6	27.8	24.4	21.7	17.8
Minimum	7.6	7.9	8.9	11.1	13.9	17.2	19.4	19.4	17.2	14.4	12.2	9.5
27.	Adana, Turkey. Latitude, 37°N; Elevation 20 m.											
Maximum	14.2	15.7	19.0	23.3	28.1	31.2	33.9	35.0	33.0	28.9	22.9	16.8
Minimum	4.6	5.6	7.6	11.0	14.9	18.9	21.9	22.4	18.9	14.6	10.4	6.6
28.	Beirut, Lebanon. Latitude, 34°N; Elevation 33 m.											
Maximum	16.4	17.2	19.3	22.4	25.8	29.0	31.3	31.8	30.2	27.2	22.6	18.5
Minimum	10.5	10.8	12.2	14.7	17.8	20.8	23.0	23.7	22.7	20.4	16.4	12.8
29.	Rehovot, Israel. Latitude, 32°N; Elevation 50 m.											
Maximum	18.2	19.4	21.8	25.7	29.0	30.4	31.9	32.3	30.9	29.4	24.7	20.2
Minimum	7.9	8.5	9.3	11.5	14.9	17.4	19.6	20.1	19.0	16.5	13.5	9.7
30.	Algiers, Algeria. Latitude, 37°; Elevation 58 m.											
Maximum	14.0	16.1	17.2	20.0	22.8	25.6	28.3	29.4	27.2	23.3	18.9	15.6
Minimum	9.5	9.5	11.1	12.8	15.0	18.3	15.6	21.7	20.5	17.2	13.3	10.6
31.	Mechra Bel Ksiri, Morocco. Latitude, 34½°N; Elevation 17–32 m.											
Maximum	18.0	19.6	22.5	24.7	27.1	31.1	34.8	34.9	32.5	28.4	22.7	19.2
Minimum	6.7	7.4	9.5	11.1	12.6	16.1	17.9	18.5	16.6	13.7	10.2	7.7

Sources: Compiled from (1) *Climate and Man, Yearbook of Agriculture, 1941.* U. S. Department of Agriculture, Washington, D.C.; (2) *Tables of Temperature, Relative Humidity and Precipitation for the World, 1958.* Meteorological Office, Air Ministry, London; (3) Official climate summary publications by Turkey and Greece; (4) Data supplied by direct correspondence with citriculture specialists in various countries.

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Table II–4

MEAN MONTHLY RAINFALL DISTRIBUTION IN SOME MEDITERRANEAN CITRUS-GROWING REGIONS

Location*	Mean Monthly Rainfall (Millimeters)†												Annual Total (Mm)	Years of Record
	1	2	3	4	5	6	7	8	9	10	11	12		
21. Valencia, Spain	34	31	39	39	42	21	12	9	75	84	50	48	397	30‡
22. Alicante, Spain	25	25	23	28	23	13	6	10	46	31	51	33	314	21‡
23. Messina, Italy	160	109	89	45	51	13	15	20	71	150	137	137	997	1946–1955
24. Taranto, Italy	41	23	33	20	25	15	10	18	25	56	46	48	360	1946–1955
25. Arta, Greece	145	125	104	76	66	28	10	10	43	147	152	174	1,080	29‡
26. Chania, Greece	109	84	46	28	15	5	3	0	15	89	66	96	556	9‡
27. Adana, Turkey	102	104	66	46	51	21	4	5	15	39	58	114	625	1929–1965
28. Beirut, Lebanon	191	158	96	51	17	3	1	0	7	47	133	188	892	1876–1957
29. Rehovot, Israel	146	97	70	14	3	0	0	0	1	13	84	152	580	1933–1955
30. Algiers, Algeria	112	84	74	41	46	15	3	5	41	74	129	137	761	1885–1937
31. Mechra Bel Ksiri, Morocco	93	85	72	52	29	8	0	1	10	52	78	97	577	1936–1956

Sources: Most of the data presented in this table were obtained by direct correspondence with citrus specialists in the various citrus-growing countries. Supplementary data and information were obtained from the following sources: (1) *Climate and Man, Yearbook of Agriculture, 1941.* U.S.D.A., Washington, D.C.; (2) *Tables of Temperature, Relative Humidity and Precipitation for the World, 1958.* Meteorological Office, Air Ministry, London; (3) official climate summary publications of Turkey and Greece.

* See Table I–3 for additional information.

† Rounded to nearest millimeter. Millimeters × 0.03937 = inches.

‡ Number of years of record; dates not available.

Table II–5

MONTHLY MEAN MAXIMUM AND MEAN MINIMUM TEMPERATURES IN VARIOUS CITRUS-GROWING REGIONS OF THE WORLD

Temperatures (°C)

Location and Temperature Range	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
32.	Kerikeri (North Island), New Zealand. Latitude 37°S; Elevation ~ 35 m.											
Maximum	24.5	25.0	23.3	21.1	18.3	16.1	15.6	16.1	17.8	19.4	21.7	23.3
Minimum	12.8	13.9	12.8	11.1	9.5	6.7	5.6	6.1	7.2	8.9	10.0	11.7
33.	Mildura (Victoria), Australia. Latitude 34°S; Elevation ~ 54 m.											
Maximum	32.0	32.2	29.1	23.6	19.3	15.8	15.3	17.7	20.0	24.7	28.4	31.2
Minimum	16.1	16.5	14.0	10.3	7.5	5.1	4.7	5.9	7.9	10.5	13.0	15.3
34.	Leeton P.O. (N.S.W.), Australia. Latitude 34½°S; Elevation 120–150 m.											
Maximum	31.6	31.5	28.1	22.5	18.2	14.2	13.7	15.7	19.3	23.2	27.3	30.2
Minimum	17.3	17.4	15.0	10.7	7.3	4.7	3.8	4.7	6.7	9.9	13.1	16.0
35.	Grahamstown (Cape Midlands), R. S. Africa. Latitude 32½°S; Elevation ~ 250 m.											
Maximum	26.7	26.8	25.8	23.2	21.8	19.9	18.9	20.3	21.6	22.5	23.2	25.8
Minimum	13.7	14.3	13.7	10.5	7.7	4.8	4.6	5.7	7.6	9.8	11.5	12.7
36.	Nelspruit (E. Transvaal), R. S. Africa. Latitude 25½°S; Elevation 610 m.											
Maximum	28.9	28.9	28.1	27.1	25.1	23.5	23.5	25.0	26.4	27.5	27.8	28.6
Minimum	18.5	18.6	17.4	15.3	10.1	6.9	6.7	8.9	12.0	15.0	16.7	17.8
37.	Mazoe Citrus Estates, Rhodesia. Latitude 17½°S; Elevation ~ 1350 m.											
Maximum	27.4	27.4	27.5	27.3	25.6	23.2	23.4	25.2	27.5	30.5	29.2	28.0
Minimum	16.8	16.5	15.6	12.5	7.9	5.1	4.3	5.8	9.4	13.4	15.8	16.4

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TABLE II-5—(CONTINUED)

Location and Temperature Range	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
38.	Campinas (S. P.), Brazil. Latitude 23°S; Elevation 720 m.											
Maximum	30.1	30.1	28.9	27.0	25.3	25.4	25.4	26.6	27.4	28.0	28.6	28.6
Minimum	18.8	18.9	18.2	15.9	13.5	11.9	13.0	12.6	14.2	16.0	16.6	17.9
39.	Corrientes (Corrientes), Argentina. Latitude 27½°S; Elevation 60 m.											
Maximum	33.9	33.3	31.6	27.2	23.9	21.1	21.7	22.8	25.6	27.8	30.6	32.8
Minimum	21.7	21.7	20.5	17.2	13.9	11.7	11.6	11.7	13.9	15.6	18.3	20.5
40.	Cañete (Lima), Peru. Latitude 13°S; Elevation 111 m.											
Maximum	28.4	29.3	29.5	28.1	24.7	21.4	20.2	20.0	21.0	22.5	23.9	26.4
Minimum	19.6	20.3	20.0	18.2	16.1	15.2	14.9	14.4	14.8	15.5	16.4	18.0
41.	Palmira (Valle), Colombia. Latitude, 3½°N; Elevation, 1006 m.											
Maximum	30.3	30.7	30.5	29.7	29.1	29.4	30.5	30.7	30.5	29.4	29.1	28.6
Minimum	17.9	18.2	18.4	18.4	18.3	18.0	17.5	17.7	17.7	17.9	18.1	18.1
42.	St. Clair Experiment Station (St. George), Trinidad. Latitude, 10½°N; Elevation, 100 m.											
Maximum	30.2	30.3	30.7	31.5	32.0	30.8	30.8	30.7	31.0	31.5	31.2	31.3
Minimum	20.1	19.7	19.9	20.7	21.4	21.7	21.7	21.9	22.1	22.0	21.7	20.9
43.	Kingston (St. Andrew), Jamaica. Latitude, 18°N; Elevation, 33 m.											
Maximum	30.5	30.7	31.7	31.8	31.9	32.7	32.9	33.1	31.9	31.5	31.3	30.5
Minimum	16.9	17.0	17.5	18.8	20.2	20.9	20.8	21.0	21.3	20.7	19.7	18.1
44.	Vera Cruz (Vera Cruz), Mexico. Latitude, 19°N; Elevation, 18 m.											
Maximum	24.7	25.4	26.5	28.2	29.8	30.4	30.6	30.7	30.2	29.4	27.0	25.6
Minimum	18.9	19.3	20.2	22.2	24.0	24.2	23.6	23.6	23.1	22.7	20.6	19.7
45.	General Teran (Nuevo Leon), Mexico. Latitude, 25°N; Elevation, 383 m.											
Maximum	17.9	23.5	26.1	30.3	34.6	35.7	36.9	36.3	33.0	30.0	22.1	20.0
Minimum	3.8	7.5	9.5	14.3	19.5	21.3	22.2	21.7	19.7	17.0	9.9	8.5
46.	Wakayama Experiment Station (Wakayama), Japan. Latitude, 34°N; Elevation, 15 m.											
Maximum	10.8	11.7	14.4	20.0	24.1	27.0	31.1	32.4	28.9	23.5	18.6	13.6
Minimum	1.4	2.0	4.4	9.2	13.7	18.3	22.7	23.4	20.1	13.9	8.7	4.4
47.	Matsuyama (Ehime), Japan. Latitude, 34°N; Elevation, 32 m.											
Maximum	9.3	9.9	13.4	18.7	23.0	26.5	30.6	31.8	28.2	22.8	17.8	12.4
Minimum	1.0	1.0	3.5	8.0	12.6	17.5	22.5	22.8	19.2	12.6	7.7	3.3
48.	Bangkhen (Bangkok), Thailand. Latitude, 14°N; Elevation, 3 m.											
Maximum	33.4	33.5	34.7	35.7	34.9	33.4	32.7	32.4	31.9	31.4	30.9	31.0
Minimum	19.3	21.4	23.1	24.5	24.7	24.6	24.3	24.4	24.1	24.0	22.5	19.5

Sources: Most of the data presented were obtained by direct correspondence with citrus specialists in various citrus-growing countries. Supplemental data and information were obtained from the following sources: (1) *Climate and Man, Yearbook of Agriculture, 1941.* U.S.D.A., Washington, D.C.; (2) *Tables of Temperature, Relative Humidity and Precipitation for the World, 1958.* Meteorological Office, Air Ministry, London; (3) official climate summary publications by Colombia, Peru, and Thailand.

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Table II–6

MONTHLY RAINFALL DISTRIBUTION IN VARIOUS CITRUS-GROWING REGIONS OF THE WORLD

Location†	Mean Monthly Rainfall (Millimeters)*												Annual Total (Mm)	Years of Record
	1	2	3	4	5	6	7	8	9	10	11	12		
32. Kerikeri, New Zealand	109	130	99	142	170	183	196	147	127	137	114	102	1,656	1948–1960
33. Mildura, Australia	19	23	18	14	26	27	23	26	24	25	21	18	264	1911–1940
34. Leeton PO, Australia	31	27	34	34	38	39	36	41	32	43	32	27	414	1914–1962
35. Grahamstown, R. S. Africa	61	67	82	56	49	34	32	36	59	76	80	63	695	1878–1950
36. Nelspruit, R. S. Africa	129	127	102	53	19	10	12	11	34	56	112	147	812	1926–1962
37. Mazoe, Rhodesia	230	202	128	28	7	3	<1	4	3	26	98	217	946	1930–1952
38. Campinas, Brazil	119	349	36	23	85	36	61	15	71	118	64	389	1,366	1929–1963
39. Corrientes, Argentina	119	114	135	142	84	48	43	38	71	119	132	132	1,177	39‡
40. Cañete, Peru	<1	2	<1	<1	5	9	2	7	6	2	2	1	38	1949–1962
41. Palmira, Colombia	77	67	86	133	117	67	28	35	55	146	112	87	1,010	1930–1955
42. St. Clair, Trinidad	69	38	46	47	88	194	222	242	185	169	180	121	1,601	71‡
43. Kingston, Jamaica	23	15	23	30	102	89	38	91	99	180	74	36	800	59‡
44. Vera Cruz, Mexico	25	16	8	30	69	244	312	338	346	162	75	31	1,656	1931–1940
45. General Teran, Mexico	11	10	18	23	84	83	7	18	64	39	24	11	392	10‡
46. Wakayama, Japan	77	74	126	166	160	258	210	170	249	131	110	77	1,808	1946–1960
47. Matsuyama, Japan	49	65	91	127	124	200	208	103	177	111	67	60	1,382	1930–1960
48. Bangkhen, Thailand	5	18	29	61	157	161	198	213	328	297	60	4	1,531	1951–1960

Sources: Most of the data presented were obtained by direct correspondence with citrus specialists in various citrus-growing countries. Supplemental data and information were obtained from the following sources: (1) *Climate and Man, Yearbook of Agriculture, 1941*. U.S.D.A., Washington, D.C.; (2) *Tables of Temperature, Relative Humidity and Precipitation for the World, 1958*. Meteorological Office, Air Ministry, London; (3) official climate summary publications of Turkey and Greece.

* Rounded to the nearest millimeter. Millimeters × 0.03937 = inches.

† See Table II–5 for additional information.

‡ Number of years of record; dates not available.

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APPENDIX III

FROST PROTECTION*

* All citations for Appendix III will be found in the bibliography to Chapter 10, pp. 437 to 446.

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Dew Point and Frosts and Freezes

The dew point is defined as the temperature to which the air must be cooled for atmospheric moisture to condense. The temperature of the dew point is directly proportional to the amount of water vapor in the air so that it is a measure of the dryness of the air. According to List (1966), the saturation vapor pressure e_w of pure aqueous vapor with respect to water is the pressure of the vapor when in a state of neutral equilibrium with a plane surface of pure water at the same temperature and pressure; e_w and e_i are temperature-dependent functions only; i.e., $e_w = e_w(T)$, $e_i = e_i(T)$. The thermodynamic dew point temperature Td of moist air at temperature T, barometric pressure p, and mixing ratio r (see equation III.2) is the temperature to which the air must be cooled in order that it shall be saturated with respect to water at the initial pressure p and mixing ratio r. The thermodynamic frost-point temperature T_f of moist air at temperature T, pressure p, and mixing ratio r is the temperature to which the air must be cooled in order that it shall be saturated with respect to ice at the initial pressure p and mixing ratio r. The dew and frost-point temperatures so defined are related with the mixing ratio and total pressure p by the respective equations:

$$e'_w(T_d) = \frac{r_w}{0.62197 + r_w} p \qquad \text{(III.1)}$$

and

$$e'_i(T_f) = \frac{r_i}{0.62197 + r_i} p.$$

The mixing ratio r of moist air is the ratio of the mass m_v of water vapor to the mass m_a of dry air with which the water is associated (List, 1966):

$$r = m_v/m_a. \qquad \text{(III.2)}$$

Per cent relative humidity U, of moist air is defined by:

$$U = 100r/r_w, \qquad \text{(III.3)}$$

where r is the mixing ratio of moist air at pressure p and temperature T and r_w the saturation mixing ratio at the same pressure and temperature (List, 1966). Relative humidity and dew point are also related in direct proportion:

$$U = e/e_s, \qquad \text{(III.4)}$$

where U = relative humidity, e = the actual vapor pressure, saturation vapor pressure over water for the dew point temperature (partial pressure of vapor in air, in mm Hg), and e_s = the saturation vapor pressure over water for the dry bulb temperature (partial pressure at saturation at the temperature of the air). However, either use of this equation or the Goff-Gratch formula in the Smithsonian Tables is not practical according to Bosen (1958). For punched card computation he has suggested the following equation:

$$U \cong \left(\frac{173 - 0.1t + t_{dp}}{173 + 0.9t}\right)^8, \qquad \text{(III.5)}$$

where t = dry bulb temperature in °F and t_{dp} is the dew point temperature in °F.

The moisture content of the air in the troposphere (from the soil surface to the stratosphere) is the principal parameter in the equation of heat transfer at night of heat accumulated by the soil, trees, and other objects at the ground surface during the day. The greater the concentration of atmospheric water vapor, the greater the fraction of heat radiation from the earth that is absorbed by the water vapor and not lost to the outer atmosphere. This accumulated heat is reradiated so that approximately 70 per cent is returned to earth (fig. III–1), while 30 per cent is lost to the stratosphere and other atmospheric

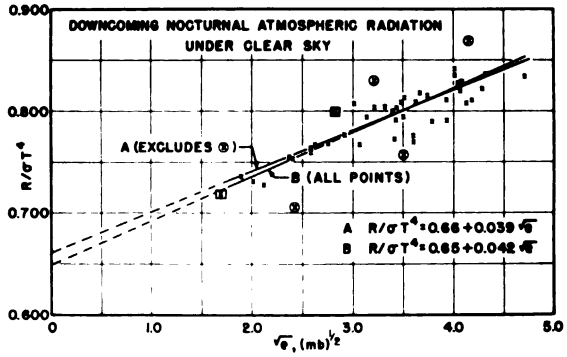

Fig. III–1. Downcoming nocturnal atmospheric radiation under clear sky. Curve *A* is for constants $a = 0.66$ and $B = 0.039\sqrt{e}$. Curve *B* is for constants $a = 0.65$ and $b = 0.042\sqrt{e}$. *R* = total long-wave downcoming atmospheric radiation under a cloudless sky, T^4 = the outgoing black body radiation at the surface temperature, *e* = the mean monthly local vapor pressure in millibars, and *a* and *b* are constants presumably variable with air mass, in the equation $R/\sigma T^4 = a + be^{1/2}$ proposed by Brunt (1939). (Goss and Brooks, 1956.)

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shells. Two equations developed by Brunt (1939) show these relationships.

If R is the downward radiation from the atmosphere to the ground on a cloudless night, the net loss of heat from the ground is B-R, where the outgoing black body radiation $B = \sigma T^4$, where σ = Stefan-Boltzman constant, and T is the ground surface temperature, and e is the vapor pressure in millibars then:

$$R/B = 0.52 + 0.065e^{1/2}. \qquad \text{(III.6)}$$

If T_1 is the ground surface temperature at sunset, T is the surface temperature t hours after sunset, k is the thermal conductivity of the ground[1] and S its heat capacity, then

$$T_1 - T = \frac{2}{\sqrt{\pi}} \frac{B\text{-}R}{\sqrt{kS}} \cdot \sqrt{t}. \qquad \text{(III.7)}$$

It is evident then that the drier the air (the lower the dew point), the greater the rate of cooling of the earth's surface, and for equal lengths of cooling periods at night, the lower the early morning temperature will be providing that the air is calm. B-R is the net radiation shown by Goss and Brooks (1956) in a chart (fig. III–2) which may be used for predicting fall in air temperature by radiational cooling. Dry air overhead usually accompanies both frosts and freezes, and the drier the air the more severe plant damage for equal durations of low temperatures, other factors remaining the same.[2] The problems posed by frost protection deal primarily with separating and weighting the importance of these factors in frosts and freezes whether natural or introduced.

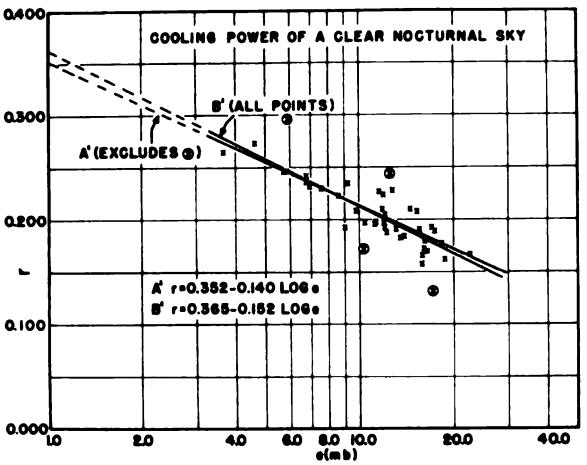

Fig. III–2. Cooling power of a clear nocturnal sky illustrated by the regression of the relative net radiation ratio, r, on the log of vapor pressure, e, when vapor pressure is measured at 2 p.m. Pacific Standard Time. In curve A', r = 0.352 – 0.140 log e, and in curve B', r = 0.365 – 0.152 log e. (Goss and Brooks, 1956.)

Heat Requirement Calculations

A basic factor influencing the amount of heat required to protect an orchard is the size of the trees, or the volume of the above-ground tissue per acre. The relation of tree age to fresh weight of top (trunk, branches, leaves, and fruit) and various fractions thereof, may be estimated from the graphs in figure III–3. Multiplying the weight of top by its specific heat and the anticipated temperature drop yields the heat which the tree needs to raise the entire tree the required number of degrees because a BTU is the amount of heat required to raise one lb of water 1° F (between 39° F and 40° F). Each kind of organ has a different proportion of the total weight of the top, and it has a different specific heat because of a different water content. Thus, reading from the graphs for a ten-year-old tree, the top weighs approximately 3.5×10^2 lb., the fruit 1.3×10^2 lb., and the leaves about 0.7×10^2 lb. The specific heat of the wood is about 0.50 BTU/lb °F (Turrell, Austin, McNee, and Park, 1967), the fruit 0.87 BTU/lb °F (Turrell and Perry, 1957), and the leaves 0.70 BTU/lb °F (Turrell, Peavy, and Austin, 1967). After applying the formula above, we have $(1.75 + 0.49 + 1.13) \times 10^2 \times 1°$ F, or a heat requirement of 3.37×10^2 BTU for one tree, or for the 100 trees in an acre, 33,700 BTU. A 10° F change would require 337,000 BTU without considering any losses to the air, soil, or sky. Obviously, this is only a small contribution on nights of severe frosts in comparison with the 4.6 to 7 million BTU per acre per hour figures Crawford showed for actual frost nights (table III–1, p. 510).

[1] Brunt (1939) calls special attention to $\sqrt{kS}$ because the nocturnal fall in temperature of the air is inversely proportional to the thermal conductivity and to the heat capacity of the soil. The rate is greatest over soils having low values of these components. In medium fine dry sand $k = 6.3 \times 10^{-4}$, with 8.3 per cent moisture $k = 1.4 \times 10^{-3}$, in other very dry soils k ranges from 4.0 to 8.0×10^{-4}, while in very wet soils k ranges from 3.0 to 8.0×10^{-3} (List, 1966). The insulating effect of dry soil and increased radiation in dry air as compared with wet may be seen in the frequency of frosts compiled by Cooper (see table 10–1, p. 341).

[2] Floyd Young (1951) stated that for equal temperatures wet weather was more dangerous than dry. This refers to peel damage, and temperature need not be especially low.

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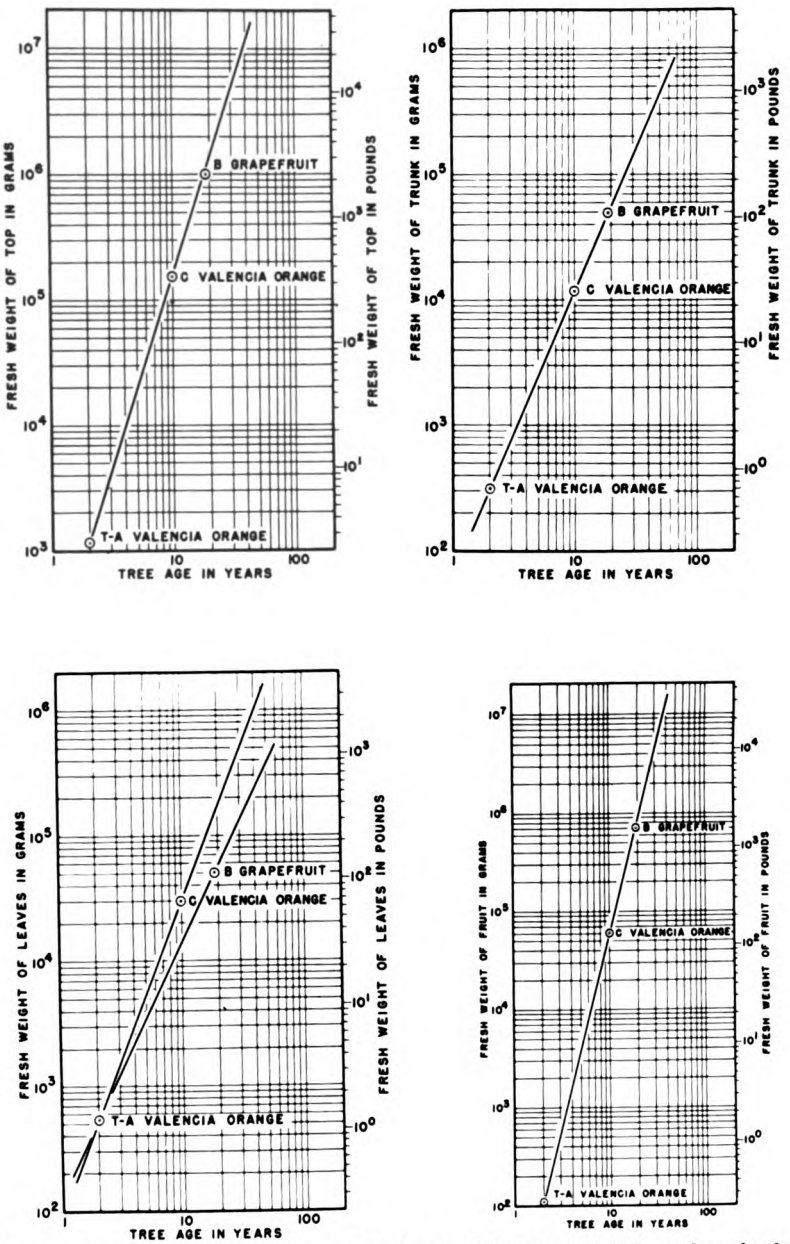
FRESH WEIGHT OF TOP IN GRAMS
FRESH WEIGHT OF TOP IN POUNDS
B GRAPEFRUIT
C VALENCIA ORANGE
T-A VALENCIA ORANGE
TREE AGE IN YEARS
FRESH WEIGHT OF TRUNK IN GRAMS
FRESH WEIGHT OF TRUNK IN POUNDS
B GRAPEFRUIT
C VALENCIA ORANGE
T-A VALENCIA ORANGE
TREE AGE IN YEARS
FRESH WEIGHT OF LEAVES IN GRAMS
FRESH WEIGHT OF LEAVES IN POUNDS
B GRAPEFRUIT
C VALENCIA ORANGE
T-A VALENCIA ORANGE
TREE AGE IN YEARS
FRESH WEIGHT OF FRUIT IN GRAMS
FRESH WEIGHT OF FRUIT IN POUNDS
B GRAPEFRUIT
C VALENCIA ORANGE
T-A VALENCIA ORANGE
TREE AGE IN YEARS

Fig. III–3. Power function plots of the rate of growth in fresh weight. Upper left, branches plus leaves plus fruit; upper right trunk; lower left, leaves; lower right, fruit. Sources: *T–A* from Turrell, Perry, Brooks *et al.*, (1926*b*); *C* from Cameron and Appleman (1934); *B* from Barnette, DeBush, Hester, *et al.* (1931).

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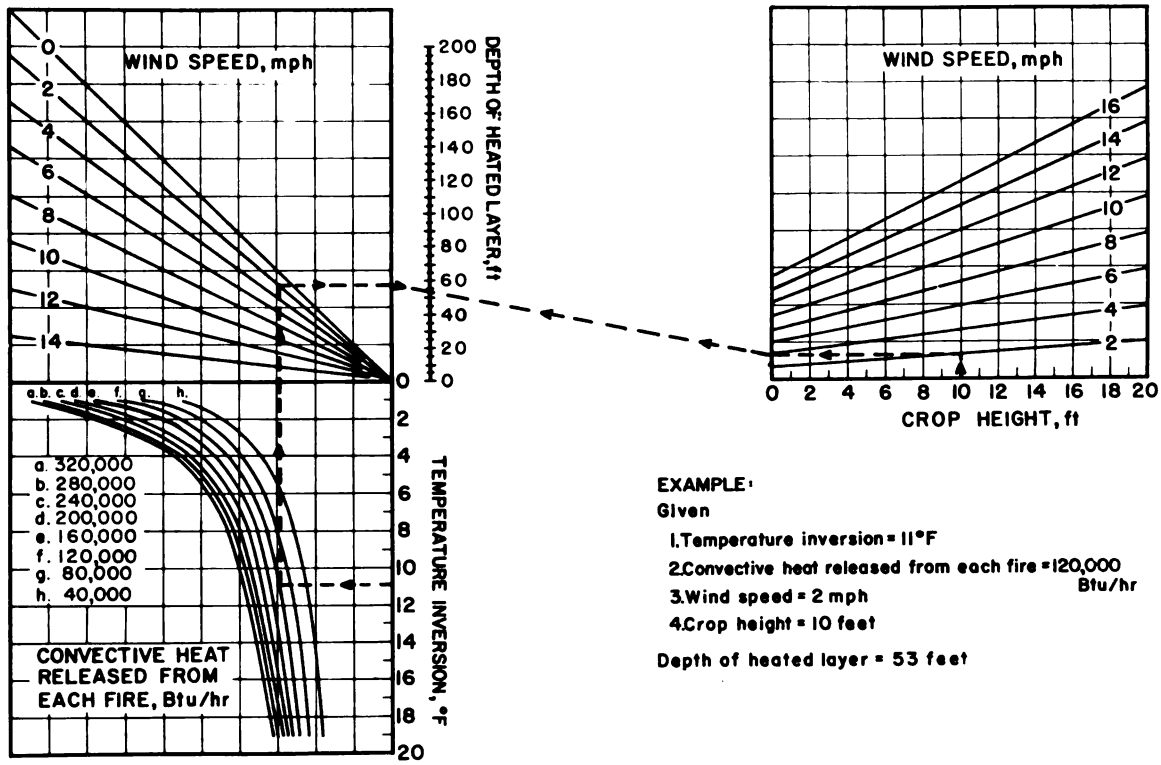

Fig. III–4. Nomograph for determining the depth of the heated layer in a heated citrus orchard. (Crawford, 1964*b*.)

Work by Crawford (1964*b*) and by Gerber (1964, 1969*b*) have made it possible to arrive at a much closer estimate of the heat requirements for any particular freeze. This is accomplished by developing a mathematical model of the heat balance in the orchard layers. The equations solved for the model have been transformed into nomograph form for quick solution for frost protection problems (Crawford, 1964*b*).

The crop zone is defined in three dimensions, and is visualized as a box. The floor of the box is the area being heated and is square; the depth of the box is determined as the height to which heating has an effect. Heat losses are by (1) radiation to the sky, (2) the air that moves through the upwind wall of the box, advection, and (3) induced flow of cold air which is drawn through the bottom part of all sides of the box as a result of the difference in relative buoyancy between heated and unheated areas. An equation can easily show the energy balance (See fig. III–5 and fig. III–6),

$$H = \text{advection} + \text{induced flow} + \text{net radiation}$$

where H is the quantity of heat added per unit area per unit time, and where advection, induced flow, and net radiation are the respective energy sinks on a per unit area basis. Windy conditions are defined here as those where the wind speeds are 16 mph.

Examples.—An estimate of the number of BTU per acre-hour required for a set of freeze conditions is made by first finding the depth of the heated layer and wind speed for a given crop height from figure III–4 and then adding the terms that are obtained from figures III–5 and III–6. An example is included for finding the depth of the heated layer in figure III–4. Simply follow the direction of the arrow on the dashed line, making an abrupt turn for each successive "given" parameter of the three different sets of conditions for the freezes shown in table III–1. A severe radiation constant of 0.8 has been employed, and $k = 0.2$ which is based on orchard B. Usually, it will be necessary to determine the height of the heated layer from figure III–4, as for table III–1. Use of the nomograph slightly underestimates the depth of the layer through which some heating influence exists. Under high net radiation conditions with a strong inversion layer, a power function fitted the data better than

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Table III–1

EXAMPLES OF METEOROLOGICAL AND ORCHARD PARAMETERS ON THREE DIFFERENT FREEZE NIGHTS

Parameters	Orchard		
	A	B	C
Temperature inversion (°F)	11.0	6.2	14.5
Convection heat released per heater (BTU hr^{-1})	81,800	81,800	74,000
Wind speed 10 ft above equivalent "O" plane (mph)	1.3	1.5	1.6
Crop height (ft)	15	15	12
Temperature difference between heated and unheated area (°F)	9.0	7.0	4.5
Height of upwind foliage (ft)	15.0	15.0	12.0
Area (acres)	15.0	15.0	1
Temperature of unheated area based on 32° F for heated area (°F)	23.0	25.0	27.5
Depth of heated layer (ft) (from fig. III–4)	51	62	43
Advection term [BTU $(acre\text{–}hr)^{-1}$] (from fig. III–5)	2.15×10^6	2.30×10^6	4.40×10^6
Induced flow term [BTU $(acre\text{–}hr)^{-1}$] (from fig. III–6)	1.25×10^6	1.10×10^6	1.40×10^6
Net radiation term [BTU $(acre\text{–}hr)^{-1}$] (from fig. III–6)	1.35×10^6	1.30×10^6	1.23×10^6
Total predicted heat	4.75×10^6	4.70×10^6	7.03×10^6
Heat actually used [BTU $(acre\text{–}hr)^{-1}$] (from Kepner, 1951)	4.62×10^6	4.62×10^6	7.20×10^6

Source: Crawford (1964*b*).

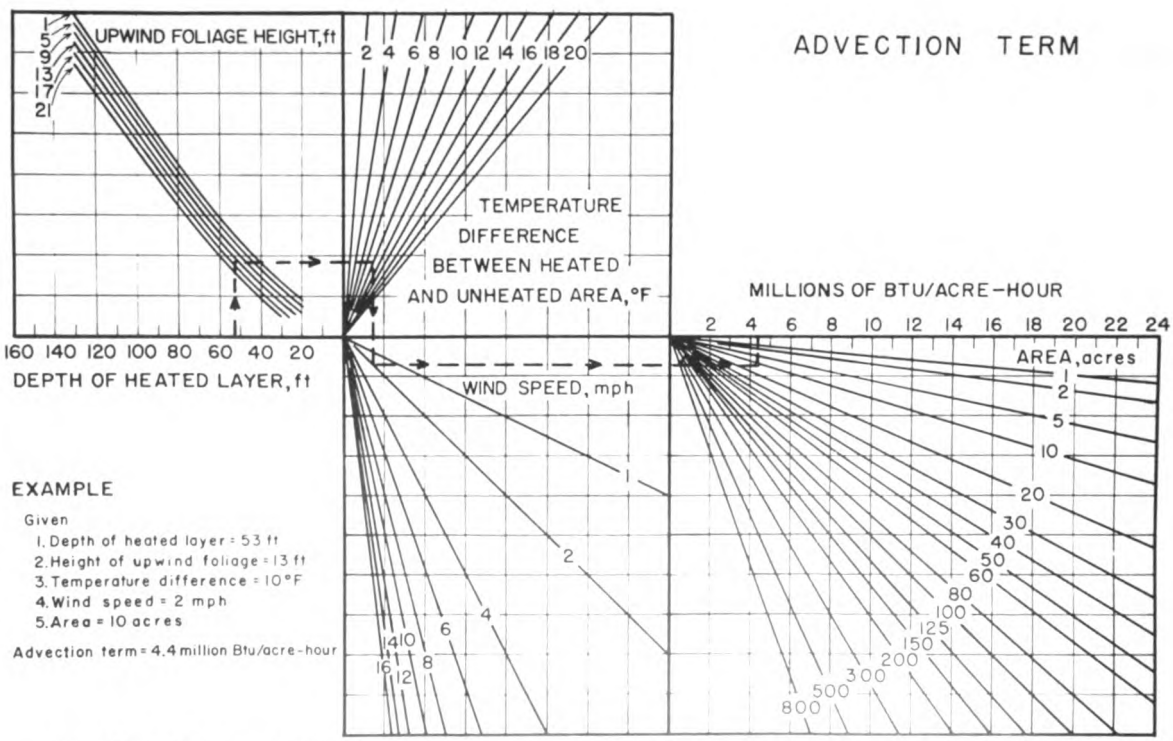
ADVECTION TERM
UPWIND FOLIAGE HEIGHT, ft
1 5 9 13 17 21
2 4 6 8 10 12 14 16 18 20
TEMPERATURE DIFFERENCE BETWEEN HEATED AND UNHEATED AREA, °F
MILLIONS OF BTU/ACRE–HOUR
2 4 6 8 10 12 14 16 18 20 22 24
160 140 120 100 80 60 40 20
DEPTH OF HEATED LAYER, ft
WIND SPEED, mph
AREA, acres
1 2 5 10 20 30 40 50 60 80 100 125 150 200 300 500 800
1 2 4 6 8 10 12 14 16
EXAMPLE
Given
1. Depth of heated layer = 53 ft
2. Height of upwind foliage = 13 ft
3. Temperature difference = 10°F
4. Wind speed = 2 mph
5. Area = 10 acres
Advection term = 4.4 million Btu/acre-hour

Fig. III–5. Nomograph for determining the advection term in a heated citrus orchard. (Crawford, 1964*b*.)

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the logarithmic function normally used. The nomograph shows this modification.

To find the advection term, refer to figure III–5. This term is the heat necessary to raise to a safe level the temperature of the damaging cold air advected into the box by a wind perpendicular to the upwind side of the box. There are two variables essential to the solution of this problem: (1) the depth of the heated layer, and (2) the height of the upwind foliage. In the example, figure III–5, simply follow the arrow direction on the dashed line, making a turn for each successive "given" parameter. The "temperature difference" between a heated and unheated area in °F refers to temperatures measured at 5 feet, the height of the standard weather bureau shelter; theoretically the figure is for 10 feet above ground.

To find the induced flow term, refer to figure III–6, the left-hand nomograph, and simply follow the arrow on the dashed line, making an abrupt turn for each successive "given" parameter in the example, as previously. This is a very brief method for finding the heat necessary to warm the cold air that flows out of the cold surrounding area into the box from all sides as a result of the lowered pressure that develops when the heated buoyant air rises. In short, it is the heat necessary to raise the invading cold air to a safe, non-freezing temperature. The heat required is calculated from (1) the depth of flow, (2) its variation with height, and (3) its magnitude. This is perhaps one of the roughest estimates in frost protection because so few measurements have been made of it. In making the nomograph, it was necessary to assume a value for v, the maximum magnitude of induced flow as 0.5 mph before Binder's (1949) energy equation,

$$v = k(\Delta T)^{1/2}, \qquad \text{(III.8)}$$

could be solved for k. This made the proportionality constant k equal to 0.2.

The net radiation term is found in figure III–6 by using the right-hand nomograph. This term is the net difference between the thermal radiation leaving the ground and trees for the sky, $R\uparrow = \sigma T^4$, and that returning from the sky, the downcoming radiation, $R\downarrow$, and is correlated with standard shelter temperatures, T, and humidities (vapor pressure, e, in mb). The constants, a and b are determined from data, where σ is the Stefan-Boltzman constant. Brunt's equation (Sutton, 1953) for incoming radiation is

$$R\downarrow = (a + be^{1/2})\sigma T^4. \qquad \text{(III.9)}$$

If a dew point of 32° F is assumed, then $(a + be^{1/2})$ becomes 0.76, but has been used in the nomograph as 0.7. For very severe outgoing radiation (very low dew points) use 0.8. Equation III.9 yields about 25 BTU/ft²/hr or about 10^6 BTU per acre/hr, which is typical net loss, $R\uparrow - R\downarrow$, in southern California. For development of this nomograph, the temperature of the unheated area characterizes the downcoming radiation, and the outgoing radiation temperature is assumed to be 32° F.

The total of the three terms in the example are: advection 4.4×10^6 BTU/acre/hr; induced flow $\equiv 1.7 \times 10^6$ BTU/acre/hr; and the net radiation term $\equiv 1.8 \times 10^6$ BTU/acre/hr or 7.9×10^6 BTU/acre/hr. By the use of table III–I, it is possible to become quite proficient in the use of the nomographs for estimating the heat requirements for frost protection. However, for an understanding of the subject, the original paper (Crawford, 1964*b*) is recommended as well as the critique by Gerber (1969*b*).

A simple alternate method of determining nocturnal heat requirements for citrus orchards has been developed by Gerber (1969*b*) from an earlier method in which heat transfer is measured for an organ and generalized to the tree basis (Gerber, 1964). The latter method will not be presented here as it has been recently published and is readily available in book form. However, it is noteworthy that Gerber's calculations show that methods of heating where heat is applied near ground level and near the skirts of the tree are more efficient than methods where the heat originates several feet above ground and some distance away from the tree.

Factors Affecting Thrust, Reach, Air Velocity, and Eddy-Current Relations of Wind Machines

The thrust has been shown by Brooks *et al.* (1952) and Crawford (1964) to be a better index of the area a wind machine can protect under California conditions than is the horsepower. The thrust F (in lb), essentially the force the airstream can exert in the axial direction, is

$$F = \bar{\rho}/g \, \frac{\pi\phi^2}{4} \, \mu_n^2 \qquad \text{(III.10)}$$

where ρ is the air density in lb/ft³, g is the gravitational conversion constant in ft/sec², ϕ, the propeller diameter in feet, and μ_n is the air velocity through the propeller circle in ft/sec.

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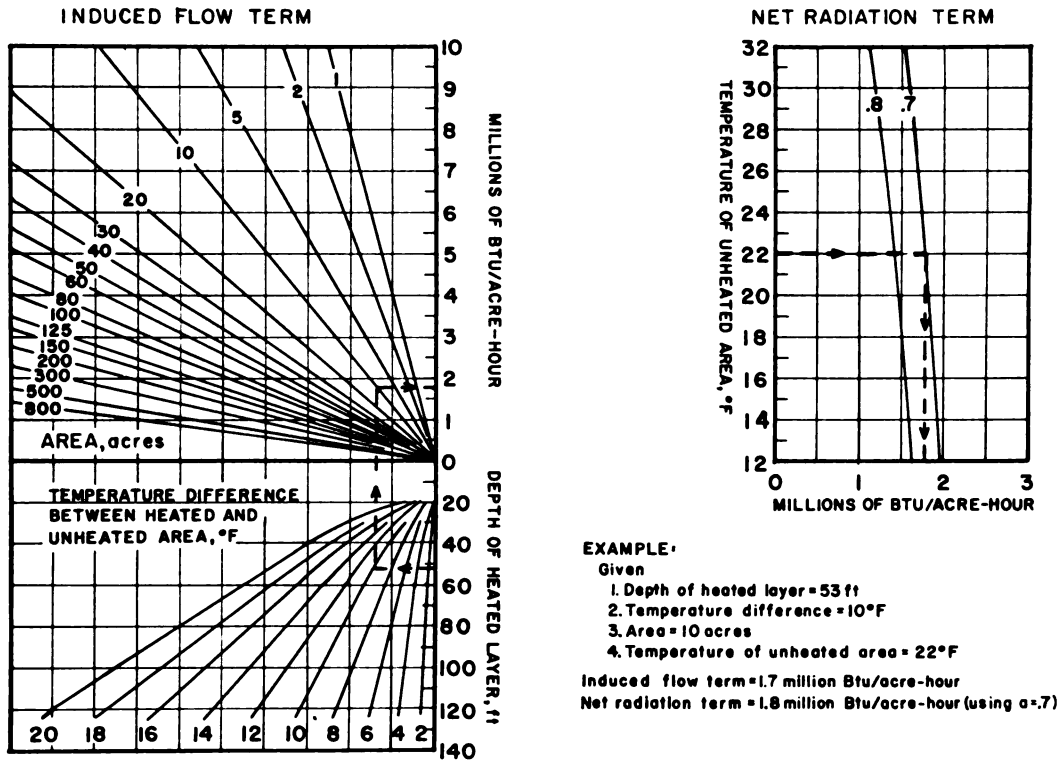
INDUCED FLOW TERM
AREA, acres
TEMPERATURE DIFFERENCE BETWEEN HEATED AND UNHEATED AREA, °F
MILLIONS OF BTU/ACRE-HOUR
DEPTH OF HEATED LAYER, ft
NET RADIATION TERM
TEMPERATURE OF UNHEATED AREA, °F
MILLIONS OF BTU/ACRE-HOUR
EXAMPLE:
Given
1. Depth of heated layer = 53 ft
2. Temperature difference = 10°F
3. Area = 10 acres
4. Temperature of unheated area = 22°F
Induced flow term = 1.7 million Btu/acre-hour
Net radiation term = 1.8 million Btu/acre-hour (using α=.7)

Fig. III–6. Nomographs for determining the magnitude of the induced flow term and the net radiation term in a heated citrus orchard. (Crawford, 1964*b*.)

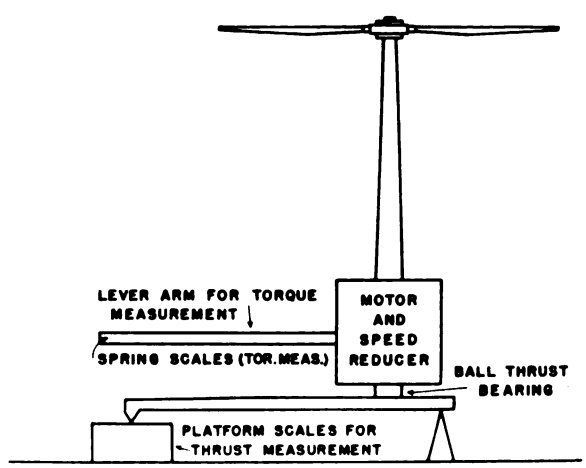
LEVER ARM FOR TORQUE MEASUREMENT
SPRING SCALES (TOR. MEAS.)
MOTOR AND SPEED REDUCER
BALL THRUST BEARING
PLATFORM SCALES FOR THRUST MEASUREMENT

Fig. III–7. Low-power test rig for measuring thrust of wind machine propellers. Strain gauges are frequently applied to measurement of thrust. (After Leonard, 1953.)

The wind machine characteristics that affect the thrust of the propeller, in lb, are the brake-horsepower of the engine, P, the power in ft.-lb per sec. measured at the propeller shaft; the propeller diameter in feet; N, shaft speed in revolutions per second; and the air density, ρ, in slugs[1] per ft^3 (ρ for dry air at 32° F = 0.00251 slugs/ft^3) where C_f is the thrust coefficient in lb per horsepower and C_p is the power coefficient in revolutions per sec, the basic relations between the factors are $P = C_p \rho N^3 \phi^5$, and $F = C_f \rho N^2 \phi^4$. Various other relations may be developed from these equations, particularly thrust, F. For example,

$$F = C_f \sqrt[3]{\rho P^2 \phi^2 / (C_p)^2}, \qquad \text{(III.11)}$$

which is the best estimate of a wind machine's performance, and one which can be determined by using a Leonard test stand (fig. III–7) (see Brooks *et al.*, 1952; Brooks, 1957).

Two factors not included in thrust that are of particular interest are air velocity and reach. Angus (1962) showed that the area protected is a

[1] One slug = a unit of mass having a weight of 32.17 lb.

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function of air velocity (and hence reach) rather than thrust. Since the temperature of the mixed air at the furthest distance from the wind machine is of importance, a compromise must be made between thrust and air speed. However, because thrust is readily calculable and measurable, wind machine efficiency will be considered in terms of thrust. A wind machine geometrically and dynamically operates like an air jet produced by a nozzle, the diameter of which corresponds to the diameter of the propeller. Since velocity profiles are similar at distances from the nozzle greater than ten times the nozzle diameter, they are mathematically similar to a Gauss distribution. This is true for wind machines if the propeller is considered equivalent to a nozzle. Then

$$\mu = \mu_o e^{-c(r/R)^2}, \qquad \text{(III.12)}$$

where μ = velocity of air parallel to jet axis (ft/sec), μ_o = velocity along axis of jet (ft/sec), r = radial distance from jet axis (ft), R = radius of jet (ft) at that where $\mu = 0.1\ \mu_o$ and where the constant, c = 2.3. Crawford (1964*a*) has developed this equation into a simplified expression relating the thrust, F, in lb, and area, A, covered by the wind machine in ft²

$$A = \frac{25F}{\mu_a^2 \rho} \qquad \text{(III.13)}$$

where μ_a = average air velocity in ft/sec (3.7 ft/sec or 2.5 mph) and ρ = air density in slugs/ft³.

The concept of eddy transfer of heat downward by wind machines was tested by a model using data from an orchard (Brooks, Leonard, Crawford and Schultz, 1961). Where

$$H_c = C_q k_H \frac{\delta T}{\delta Z}\ (B/hr\ ft^2) \qquad \text{(III.14)}$$

is the equation of heat transfer in which H_c is the convective heat flux in BTU/hr/ft², C_q equals volumetric heat capacity of air in BTU/ft³/°F, k_H equals eddy conductivity, in ft²/sec, and $\frac{\delta T}{\delta Z}$ is the temperature-height gradient in °F/ft and their absolute values are –0.02, 0.14, and 0.18 respectively divided by 0.26, then the value of H_c is –6.96 BTU/hr/ft². This downward convection amounts to about 25 per cent of the net radiation loss to the cold sky or 2.14×10^5 BTU/hr/acre (B in ft⁻¹ is 0.0713 $\gamma_o A/FT_o$), where A in degrees F/ft is the temperature gradient in the inversion, F in lb_f is the thrust of jet momentum flux, T_o in °R is the absolute temperature of the air, and γ_o in lb_f/ft³ is the specific weight of the air at the cone apex.

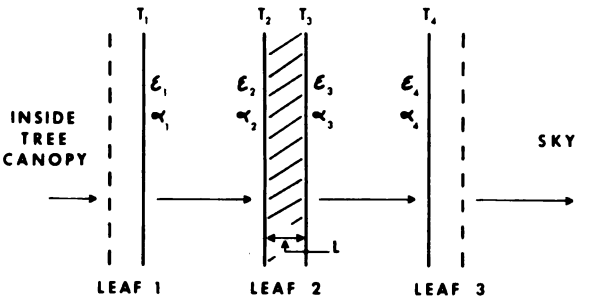

Fig. III–8. Diagrammatic illustration of three citrus leaves, forming radiation shields between inside of tree and sky. These are postulated to be infinite planes with no convection.

Mode of Action and Effectiveness of Radiation Shields

A solid body struck by an infrared beam absorbs part of the beam at the surface (absorptivity, α) and reflects part of the beam (R, reflectivity). The portion of the beam absorbed will be re-emitted at a long wavelength in the infrared, the wavelength being directly dependent on temperature. The temperature in turn is a function of the radiation, convection, and conduction properties of the body. But the quantity of infrared emitted is a function of the physical properties of the emitting surface, which is termed the emissivity, ϵ. Emissivity of a gray body is stated as a fraction of the percentage of emissivity of a black body which is 1.00.

If we consider the action of three tiers of leaves on a citrus tree at night and compare the radiation with that of three tiers of boards in the roof of an instrument shelter, one leaf on the surface of the tree in full view of the sky, and one just below it where it sees only the first leaf and no sky, and a third further in the tree which sees only the second leaf, then this situation can be diagrammed as shown in figure III-8. The same figure may also be used to illustrate heat transfer between the three roof boards in an instrument shelter. The calculations are the same for both. The rate of radiant heat flow, q/A, in BTU, per unit leaf area, A, in ft², in this system may be roughly assessed by the following equation when

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the area of the leaf is large compared to the distance between leaves:

$$q/A = \frac{K}{\frac{1}{\alpha_1} + \frac{1}{\alpha_2} - 1}\left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right], \quad \text{(III.15)}$$

where [K is the Stefan-Boltzman constant (1.713×10^{-9} BTU ft^{-2} °R^{-4} hr^{-1}) $\times$ 100^4], α is the absorptivity for thermal radiation, and T is leaf temperature in degrees Rankine. In the following development of equation III.5, ϵ is the emissivity, F is the configuration factor for net radiation from area A_1 to area A_2, h_r is the radiation heat transfer coefficient in BTU per hr ft^2 °F, k is thermal conductivity in BTU per hr ft^2 °F per ft, L is the leaf thickness in feet, and T is leaf temperature in degrees Rankine. To illustrate assume the leaves are infinite parallel planes, that there is no convection, the heat to be transferred is $0.00672 = \frac{K}{100}$ in BTU per hr ft^2 °F per ft and it is equivalent to $\frac{K}{100}$ in kg cal per hr m^2 °C per m = $\frac{\alpha K}{100}$ or 0.00002778 gm cal per sec cm^2 °C per cm. The solutions to radiation shield problems have been treated by a number of workers (Boelter, *et al.*, 1945*b*; Carslaw and Jaeger, 1959; De Barr, 1948; Garrison and Lawson, 1948; Jakob and Hawkins, 1957; Lawson and Fano, 1947; and Poppendiek, 1949), all of whom dealt with shields of both finite and infinite thermal conductivity.

The fourth degree equation (III.15) may be transformed to a simpler one without significant loss by eliminating the term equal to 1,

$$1 + \left(\frac{T_1 - T_2}{T_1 + T_2}\right)^2$$

that appears in the equation above to obtain the equation below. Then

$$q/A = 0.00685\, F_{\epsilon_{1,2}}\left(\frac{T_1 + T_2}{200}\right)^3 (T_1 - T_2), \quad \text{(III.16)}$$

$= h_{1,2}\,(T_1 - T_2)$ where h is the surface conductance in BTU per hr ft^2 °F per ft, and since $\alpha_1 = \epsilon_1$, etc., for infinite parallel planes

$$F_{\epsilon_{1,2}} = \frac{1}{\frac{1}{\alpha_1} + \frac{1}{\alpha_2} - 1} \quad \text{(III.17)}$$

$$= \frac{0.1713}{\frac{1}{\alpha_3} + \frac{1}{\alpha_4} - 1}\left[\left(\frac{T_3}{100}\right)^4 - \left(\frac{T_4}{100}\right)^4\right] \quad \text{(III.18)}$$

$$= 0.00685\, F_{\epsilon_{3,4}}\left(\frac{T_3 + T_4}{200}\right)^3 (T_3 - T_4) \quad \text{(III.19)}$$

From (III.16)

$$(T_1 - T_2) = q/A \,\frac{1}{0.00685\, F_{\epsilon_{1,2}}\left(\frac{T_1 + T_2}{200}\right)^3} \quad \text{(III.20)}$$

From (III.17)

$$(T_2 - T_3) = q/A\,\frac{L}{k} = q/A\,\frac{1}{k/L} \quad \text{(III.21)}$$

From (III.18)

$$(T_3 - T_4) = q/A \,\frac{1}{0.00685\, F_{\epsilon_{3,4}}\left(\frac{T_3 + T_4}{200}\right)^3} \quad \text{(III.22)}$$

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$$\Sigma(T_1 - T_4) = q/A \frac{1}{0.00685\, F_{\epsilon_{1,2}} \left(\frac{T_1 + T_2}{200}\right)^3} + \frac{1}{k/L} + \frac{1}{0.00685\, F_{\epsilon_{3,4}} \left(\frac{T_3 + T_4}{200}\right)^3} \quad \text{(III.23)}$$

$$h_{r_{1,2}} = 0.00685\, F_{\epsilon_{1,2}} \left(\frac{T_1 + T_2}{200}\right)^3 \quad \text{(III.24)}$$

$$h_{r_{3,4}} = 0.00685\, F_{\epsilon_{3,4}} \left(\frac{T_3 + T_4}{200}\right)^3 \quad \text{(III.25)}$$

$$q/A = \frac{1}{\frac{1}{h_{r_{1,2}}} + \frac{1}{k/L} + \frac{1}{h_{r_{3,4}}}} (T_1 - T_4) \quad \text{(III.26)}$$

Example.—Let us now add some established physical constants to the diagram in figure III-8. Let $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = 0.87$, the known emissivity of lemon leaves, $k = 0.0479$ BTU per ft² hr °F per ft (2.0×10^{-4} cal/cm² sec °C per cm), the known thermal conductivity of fresh citrus leaves, and let t_1 be 30° F and T_1 be 490° R, t_4 be –10° F and T_4 be 450° R, and leaf thickness be 250μ or 0.00082 ft. Then

$$\frac{1}{\frac{1}{\alpha_1} + \frac{1}{\alpha_2} - 1} = \frac{1}{\frac{1.00}{0.87} + \frac{1.00}{0.87} - 1}$$

$$= \frac{1}{2.298 - 1} = 0.770$$

which is a non-dimensional ratio.

A rough estimation follows:

$$T_2 = T_3 = \frac{T_1 + T_4}{2} = \frac{(460 + 30) + (460 - 10)}{2}$$

$$= \frac{490 + 450}{2} = \frac{940}{2} = 470°R$$

$$h_{r_{1,2}} = 0.00685 \cdot 0.77 \left(\frac{490 + 470}{200}\right)^3 = 0.583$$

$$h_{r_{3,4}} = 0.00685 \cdot 0.77 \left(\frac{470 + 450}{200}\right)^3 = 0.513.$$

Then T_2 is

$$T_1 - T_2 = q/A/h_{r_{1,2}} = \frac{10.68}{0.583} = 18.32°$$

$$T_2 = 490 - 18.32 = 471.68°R$$

and T_3 is

$$T_2 - T_3 = q/A/k/L = \frac{10.68}{58.3} = 0.183°$$

$$T_3 = 471.68 - 0.183 = 471.50°R$$

$$T_3 - T_4 = q/A/h_{r_{3,4}} = \frac{10.68}{0.513} = 20.82°$$

$$T_4 = 471.50 - 20.82 = 450.68°R$$

$$\Sigma(T_1 - T_2) + (T_2 - T_3) + (T_3 - T_4) = 39.32°$$

Further calculations will show that the interpretation of the leaf having surfaces 2 and 3 to act as a radiative shield between leaves having surfaces 1 and 4 (see fig. III–2), reduced the heat rate by half, even though there was little temperature difference between the upper and lower surfaces of the middle leaf. The efficiency of a thin leaf with low K is greatly different than that of a thin shield of high K. See n shields = 1 as shown in fig. III–9.

It is instructive to compare the calculated parameters for leaves acting as radiation shields with the roof of a weather shelter, as shown in *B* of figure 10–37 (p. 386), given the same temperature difference for inside and outside the models, and determined values of k and ϵ for fresh leaves (Turrell, Peavy, *et al.*, 1967) and for fresh wood (Turrell, Austin, *et al.*, 1967). The assumed, given, and computed values are shown

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Table III–2

ASSUMED VALUES AND CALCULATED TEMPERATURES OF CITRUS LEAVES AND ROOF OF A WEATHER SHELTER ACTING AS RADIATION SHIELDS

Example I Citrus Leaf	Example II Wood Weather Shelter
Assumed:	
$k = 0.0479$ BTU/ft² hr °F/ft	$k = 0.150$ BTU/ft² hr °F/ft
$L = 0.00082$ ft $\equiv 250\ \mu$	$L = 0.625$ ft $\equiv$ ¾ inch
Let $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = 0.87$	$\alpha = \epsilon = 0.95$
$t_1 = 30°$ F, $t_4 = -10°$ F	$t_1 = 30°$ F, $t_4 = -10°$ F
$T_1 = 490°$ R, $T_4 = 450°$ R	$T_1 = 490°$ R, $T_4 = 450°$ R
Calculated:	
$\frac{1}{\frac{1}{\alpha_1}+\frac{1}{\alpha_2}-1} = 0.770$	$\frac{1}{\frac{1}{\alpha_1}+\frac{1}{\alpha_2}-1} = 0.905$
$h_{r_{1,3}} = 0.583$	$h_{r_{1,2}} = 0.686$
$h_{r_{3,4}} = 0.513$	$h_{r_{3,4}} = 0.603$
$k/L = 58.3$	$k/L = 0.240$
$q/A = 10.86$	$q/A = 5.49$
$T_1 - T_2 = 18.32$ $T_2 = 471.68$	$T_1 - T_2 = 8.00$ $T_2 = 482.00$
$T_2 - T_3 = 0.183$ $T_3 = 471.50$	$T_2 - T_3 = 22.88$ $T_3 = 459.12$
$T_3 - T_4 = 20.82$ $T_4 = 450.68$	$T_3 - T_4 = 9.10$ $T_4 = 450.02$

in table III–2. The radiation $h_{(r_1, _2)}$ from leaves was lower than that for the shelter roof. Also, the radiation ($h_{r_3, _4}$) for the leaves was lower than for the shelter roof. The quantity of heat conducted through the shields was much greater in the thin leaves as indicated by k/L than through a thick board. Quantitatively, this is indicated by the ratio q/A which was almost twice as high for the leaves as for the shelter top. It is, of course, interesting to see the greater temperature drop in the center board of the shelter top as compared with that of the center leaf ($T_2 - T_3$) (see table III–2). Actually, the radiation shield position of greatest interest is the one facing the sky. All thermometers, thermocouples, thermistors, and thermograph elements must be carefully shielded from the sky if they are to give true air temperatures. A mathematical treatment of infrared radiation between a solid surface and a gas is given by McAdams (1954) and new tables for the atmosphere have been prepared by Elsasser and Culbertson (1960). Measured and calculated temperatures of citrus leaves (Turrell, Austin, and Perry, 1962) on the surface of trees compare favorably with those for $T_3 - T_4$ in table III–2.

The effect of the number of radiation shields between radiation source and receiver is shown in figure III–9. Emissivity of citrus leaves is about 0.87. Thus the efficiency of the leaves of the tree would be very low if they were thermally very conductive. However, they have a very low thermal conductivity, so that the canopy of mature citrus trees has very good insulative properties as shown in figure III–10. The rate of heat transfer between two parallel flat plates when convection is absent is directly proportional to K, A, and $\triangle t$, and inversely proportional to the distance between plates (McAdams, 1954).

The degree of effectiveness of a transparent plastic covering (R_n) against net radiation loss

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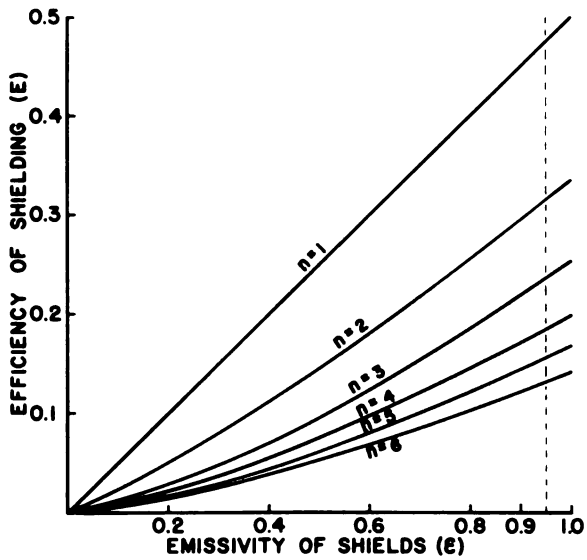

Fig. III–9. Efficiency coefficients (E) for a number (n) of identical thin radiation shields of high thermal conductivity and varying emissivities (ϵ). E = 0 corresponds to perfect shielding, and E = 1 corresponds to 0 shielding. (After Lawson and Fano, 1947.)

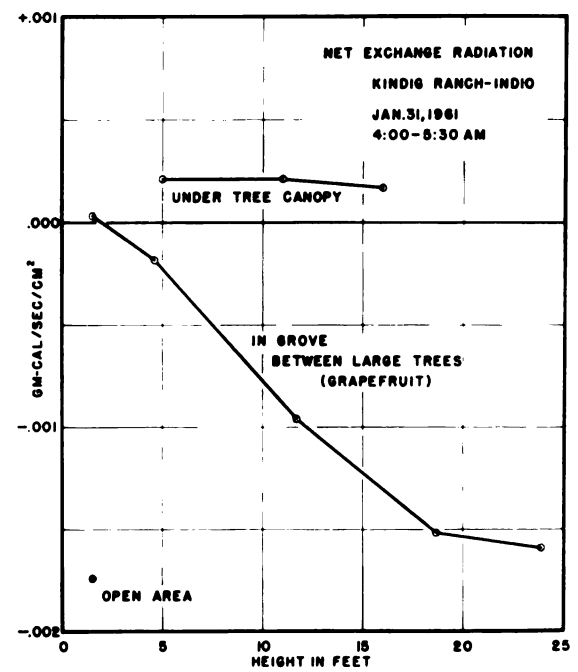

Fig. III–10. Net exchange radiation (hemispherical) measured with the Beckman-Whitley radiometer under the tree canopy of a large grapefruit tree at various heights between the trees, and in an open sandy area nearby. The graph shows the effect of a number of thin, thermally nonconducting leaves. (From Turrell and Austin, 1965.)

equals protection index (PI) and may be calculated from the following equation:

$$PI = 10^2\left[1 - \left(\frac{R_n \text{ (with cover)}}{R_n \text{ (without cover)}}\right)\right] \quad \text{(III.27)}$$

where PI ranges from 0 (no protection) to 100 per cent or complete protection. PI measured in the field were window glass 93 per cent, polyvinylfluoride 90 per cent, polyester 87 per cent, polystyrene 63 per cent, polyethylene 26 per cent (Hanson, 1963). The transmittance of these films in visible, near, and terrestrial infrared are shown in figures 10–28 (p. 373). Cahoon *et al.* (1963) showed that temperature increases under plastic shields did, in fact, accelerate growth. Protection against advection freezes with them, however, appears to be better than against radiation frost. In any event great care must be exercised in their selection and use. (See Lee, 1973.)

Windspeed, Transpiration, and Tissue Desiccation

The relative effect of high wind velocities on desiccating plant tissues can be visualized using evaporation from a free water surface as a model. The drying potential must be first determined (Lurie and Michailoff, 1936). This can be obtained from the pressure difference between saturated steam at the temperature of the wet bulb thermometer, H in mm Hg, and the partial pressure of steam, h in mm Hg, at the temperature and saturation of the moving air. Since the dry-bulb (t_c) and wet-bulb (t_m) temperatures were obtained by experiment, the pressure difference can be found using the Regnault equation:

$$H - h = Ab(t_c - t_m) \quad \text{(III.28)}$$

where $b \equiv$ barometric pressure in mm Hg, A = psychrometric coefficient depending on air velocity (v = average air velocity at a distance in meters/sec). A is equal to $1 \times 10^{-5}\left(\frac{65 + 6.15}{v}\right)$. The rate of evaporation is a linear function of air velocity (1.1 to 7.5 meters/sec). That is

$$\frac{W}{ZF} = C(H - h) \quad \text{(III.29)}$$

in which the coefficient, $C = 22.0 + 16.8$ v gm m^{-2} hr^{-1} mm^{-1} Hg partial pressure difference, at absolute humidity 5 to 100 gm/m^3. W = weight of water evaporated in gm; Z = time in hr; F = evaporation surface in m^2; H = water vapor pressure at temperature of liquid evaporated in mm Hg; h =

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partial pressure of water vapor in air in mm Hg; C = rate of evaporation for which the following values were determined: low air velocity, $C = 33$ gm m^{-2} hr^{-1} (mm Hg) $^{-1}$; moderate, $C = 42$; high, $C = 52$.

Jensen (1954) derived a simple equation relating transpiration rate to wind velocity:

$$E = (3.7 + 0.5U^{0.8})d \qquad \text{(III.30)}$$

where U = horizontal wind speed in meters sec^{-1}, d = vapor pressure deficit which was obtained by subtracting an arbitrary constant air vapor pressure ($P_s = 0.1897$ lb in^{-2}) from the saturated vapor pressure P_t, corresponding to the average measured air temperature at a given location, E = transpiration rate in gm hr^{-1} m^{-2} of leaf area. Absolute humidity (d_s) = 570.12×10^{-6} lb ft^{-3}. Jensen's equation does not take into consideration the dimensions of the leaf in relation to direction of wind. The water loss of the leaves of citrus trees can better be examined by using the model developed by Martin (1943) for leaves (*Helianthus*) and filter paper evaporimeters. The effect of wind flowing at different directions to the body, at right angle to and parallel to it is shown in the following equation:

$$E = CK''(P' - P'')R^m L^n W^x \qquad \text{(III.31)}$$

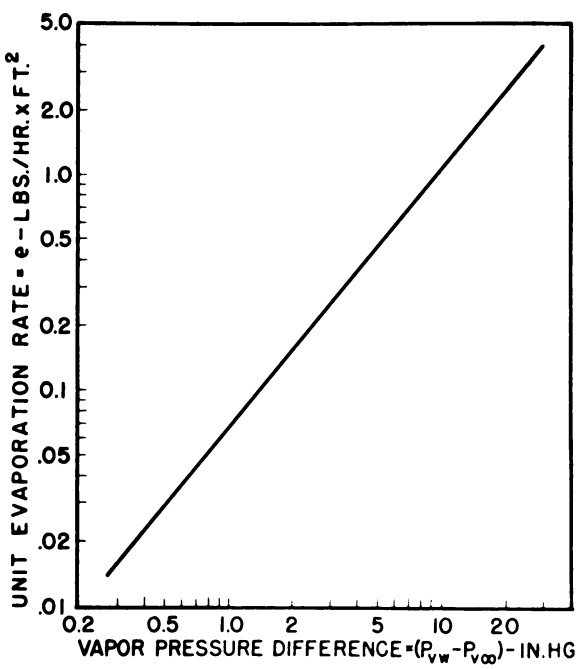

Fig. III-11. The relationship between evaporation rate and vapor pressure difference. (After Boelter *et al.*, 1946*a*.)

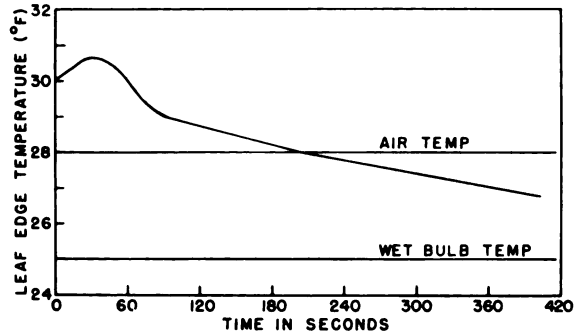

Fig. III-12. Effect of wind, showing leaf edge temperature approaching the wet bulb temperature of the air when sprinkling is stopped (time, 400). (From Wheaton and Kidder, 1964.)

where E = rate of evaporation in gm hr^{-1} dm^{-2}; C = dimension conversion factor in sec hr^{-1} (0.73); K'' = diffusion coefficient ($W_o = 0.10$, $W_{250} = 0.335$ where subscripts = cm sec^{-1} in gm dm^{-2} $sec^{-½}$ $(mm\ Hg)^{-1}$; P' = vapor pressure at the evaporating surface in mm Hg; P'' = vapor pressure at the outer edge of the boundary layer in mm Hg; R = dimension at right angle to air flow in cm (m = –0.2); L = dimension parallel to air flow in cm (n = –0.3); W = wind velocity in cm sec^{-1} (x = +0.5). A recent treatment has confirmed these results in a general way (Parkhurst, Duncan, Gates, *et al.*, 1968). These models show that (1) wind of high velocity can induce high transpiration rates, (2) a large vapor pressure difference between leaf and air (i.e., dry air) can induce a high transpiration rate, (3) that the two factors when operating together, as with the north wind, can induce very high transpiration rates, indeed.

The equation describing evaporation from an open pan of water under quiet conditions is as follows:

$$e = 0.067(P_{vw} - P_{v\infty})^{1.22} \qquad \text{(III.32)}$$

where e is the evaporation rate, P_{vw} is the vapor pressure of water vapor on the gaseous side of the liquid-gas interface and $P_{v\infty}$ is a similar vapor pressure at a large distance away (Boelter, Gordon, and Griffin, 1946*a*). This relation is shown graphically in figure III-11. To this a correction coefficient could be applied for the kind of plant, and plant part and the degree of desiccation determined or linear inverse curves could be drawn for the relation between relative humidity and transpiration (Darwin, 1914; Bialoglowski, 1936; Thut, 1938, 1939; Martin, 1943). Cooper (1963*a*) reported the desiccated appearance of leaves and

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Fig. III–13. The effect of overhead sprinkling in January, 1962, on young citrus trees in the dry atmosphere of a freeze in southern California on the John Bidart property, Kern County. (Photo courtesy Robert G. Platt.)

Fig. III–14. Murcott Honey orange orchard near Orlando, Florida, killed by overhead sprinkling in the dry advection freeze of December, 1962.

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the high damage to twigs in Florida, and it was estimated that more than 50 per cent of the damage in the severe California freeze of 1913 was a result of desiccation (Carpenter, 1914). Vasil'yev (1961) contends that in Russia winter desiccation is one of the major factors in the frost killing of plants.

The effect of a dry wind is to induce strong cooling by evaporation from the plant parts that do not see the sky as well as those that do. In a study on the effect of evaporation on frost protection Wheaton and Kidder (1964) showed that transpiration from a leaf in a wind tunnel where the air was moving 6.6 mph and radiation losses were excluded, could reduce the temperature of a wet or ice-covered object below air temperature, and the minimum temperature to which a surface such as a leaf could be cooled by evaporation was the wet bulb temperature of the air as seen in figure III–12. Miller (1963*b*) showed in the 1962–63 freeze in California that leaves of grapefruit trees subjected to low sprinkling were 3.2° F to 4.8° F colder than air at the same positions on the trees. The dew point was –8° F so that the wet bulb temperature could have approached 20° F, but wet leaf temperatures (30.6° F to 31.5° F) although below water freezing temperatures were above freezing temperatures of leaf tissues. Ice formation was considerable, however, with results which are often disastrous in dry areas such as southern California (see fig. III–13). It also should be remembered that for sky-exposed plant parts, such a dry atmosphere (dew point of –8° F) as mentioned here may cause lower temperatures than wet bulb temperatures because of the increased radiation rate to the sky permitted by an extremely dry atmosphere. Complete defoliation followed the overhead sprinkling of oranges because of the dryness of the wind in the 1962 freeze in Florida (see fig. III–14).

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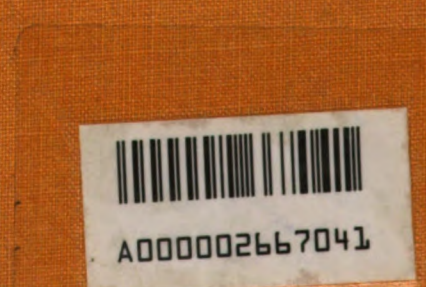

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